December 1956

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NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION

NUCLEONICS GOES ABROAD TO REPORT ON...

Why Britain Claims World Lead in Nuclear Power

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PYROPHORICITY

A Mystery Under Attack

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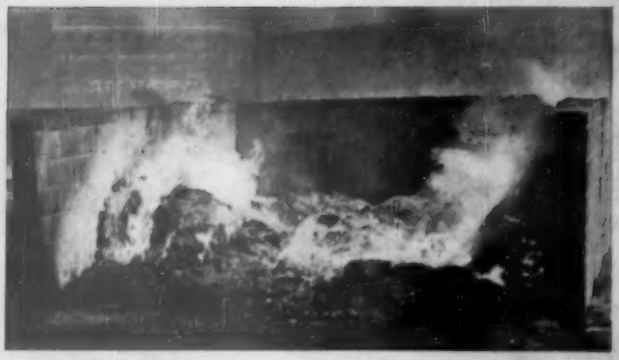

New General Electric Atomic Lab to Help Cut Cost of Nuclear Power

The new General Electric Vallecitos Atomic Laboratory in Pleasanton, California, will develop and test new ideas aimed at reducing the cost of atomic-generated electric power.

The new laboratory, to begin operation in 1957, will initially consist of a Critical Assemblies Building (1), a Radioactive Materials Lab. (2), and a full-scale developmental Boiling Water Reactor (3).

The Boiling Water Reactor will permit tests of both natural and forced circulation, core configuration experiments, and either single- or dual-cycle operation. Steam produced in this reactor will also be used, through a joint arrangement with Pacific Gas & Electric Co., to generate the first all-privately-financed atomic-electric power.

The Vallecitos Atomic Laboratory is further evidence that General Electric will maintain engineering leadership in the field of atomic energy.

Atomic Power Equipment Department, General Electric Company, San Jose, California. 196-2

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NUCLEONICS

DECEMBER • 1956

Vol. 14, No. 12

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AMF ATOMIC

With the start-up of this new pool-type research reactor, at Battelle Memorial Institute, Columbus, Ohio—a world leader in industrial research has become *the* world's leader in private *nuclear* research.

The new Battelle research reactor, designed and built by AMF ATOMICS, has a power output of 1,000 kilowatts, and is the most powerful and most flexible privately owned research reactor yet to go "critical". Under the direction of Dr. H. R. Nelson and an outstanding staff of nuclear scientists, Battelle now offers industry extensive facilities for studies in a wide range of atomic energy applications.

The newly completed reactor is the first of *eight* AMF research reactors scheduled for completion within the next 24 months. Highly flexible in its application, it is the most economical type of reactor to provide such large experimental capacity and high

• *Research and Power Reactors* • *Food Irradiation Equipment* • *Control Rod Drive Systems* • *Remote Materials Handling Equipment*

RESEARCH REACTOR at Battelle

The world's most versatile privately owned research reactor now in operation

flux levels. Incorporating the most advanced safety features, it is ideally suited for university and industrial research installations.

Other AMF-designed research reactors include light and heavy water tank types using enriched fuel—natural uranium heavy water systems—as well as zero power installations.

In the power reactor field, AMF has developed a closed-cycle boiling-water system which offers nuclear power at a cost competitive with conventional fuels in many areas of the world.

For a complete "turnkey" reactor facility, from conceptual planning through initial operation...for individual components... for technical assistance during any phase of your nuclear program... contact AMF ATOMICS, the world's leading designer and producer of research reactors.

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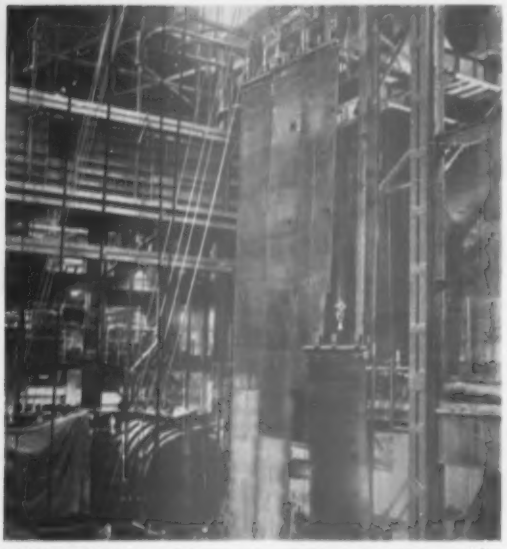
B&W AND ATOMIC ENERGY 6

How to Put

TONS OF CONCRETE, poured into this web of wire, will form walls of B&W-engineered swimming pool type research reactor.



SUPERCRITICAL pressure steam generator, the world's first, saw B&W engineers solve new design, fabrication, and erection problems.

ERECTION means smooth flow of components into place. Here side wall of high pressure, high temperature boiler is prepared for hoisting.

HERE ARE THE REASONS WHY B&W ENGINEERS KNOW...

a Nuclear Reactor Together

Putting a nuclear reactor together is an exacting engineering task. Research and power reactors are designed and fabricated to meet specific needs. But design and fabrication alone will not assure required operating characteristics. It's the job of the erection engineer to precisely assemble components into a working system.

SAFETY AND ECONOMY in assembling and testing research reactors and nuclear steam generating plants require skill in established construction methods. But with this skill, there must be combined advanced scientific and nuclear engineering techniques. B&W erection engineers have already acquired an extensive backlog of atomic energy experience, and are keeping up with the fast moving developments in the peaceful applications of this new source of energy.

LONG EXPERIENCE with high pressure vessels for example, has been applied by B&W to atomic energy's similar problems. It has been fortified by a continuing, independent program of nuclear research to make the Babcock & Wilcox position unique in design, fabrication, and erection for the atomic energy field.

STEP BY STEP, B&W engineers have followed progress in design and fabrication with improvements in erection methods. New techniques and tools have been developed and tested. Alloy welding, radiography, magnafluxing, and stress relieving processes have been adapted to the particular needs of erection.

HIGHLY SKILLED EXPERTS with special training supervise erection. Precision is their watchword and the newest techniques are at their finger-tips. Behind them stand nearly 100 years of B&W experience and the entire chain of specialized B&W engineering skills.

COORDINATION of all B&W departments assures a continuity of responsibility in one company from planning to starting up operations. Write for Bulletin AED-6, "B&W Builds a Research Reactor." The Babcock & Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, N. Y.

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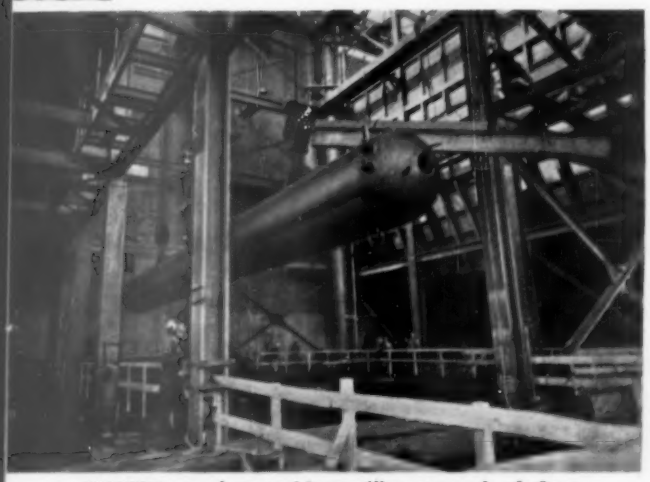
ATOMIC ENERGY DIVISION



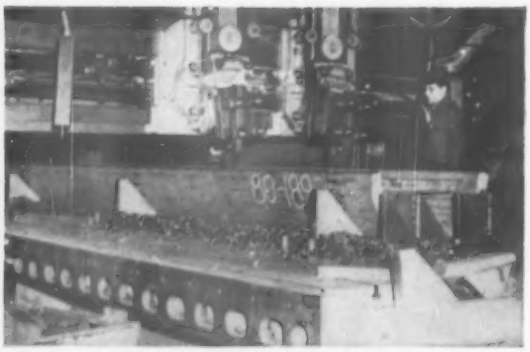
KNOTTY erection problems, like removal of floor member to hoist drum into position, are taken in stride by specially trained engineers.

B&W'S STORE of high pressure welding experience is added to newest welding metallurgy refinements required for atomic energy projects.

AE-37

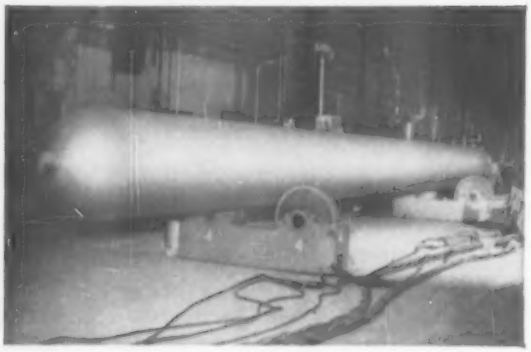
FOSTER WHEELER FABRICATES "T-1" STEEL

Bending 2 in. "T-1" steel plate on 8000-ton beam press



Machining mating surfaces of half shell

Automatic welding of exterior seam



One of nine vessels nearing completion

THE FORMING and welding of high-yield-strength "T-1" steel has been extensively investigated by Foster Wheeler and a number of pressure vessels have now been successfully fabricated of this new material. Operations in the manufacture of one of these vessels are shown above.

The 8000-ton beam press at Foster Wheeler's Mountaintop, Pa., plant was used to form the flat "T-1" steel plate, 2 in. thick, into half shells which were machined and welded into a full cylinder. Bending techniques were developed and conservative limits established to control maximum bending stresses. The toughness of the steel was unaffected by cold bending within these established limits.

After exploring several welding processes, the automatic submerged melt technique was found most satisfactory, meeting the required joint efficiency of 100 percent in the stress relieved condition.

For end closures, where inside back welding could not be used, a procedure was developed for 100 percent penetration welding without backing strips.

Foster Wheeler's specialized experience and extensive shop facilities are available for the heavy fabrication of "T-1" steel or other high-yield strength steels. For further information, write to *Foster Wheeler Corporation, 165 Broadway, New York 6, N.Y.*

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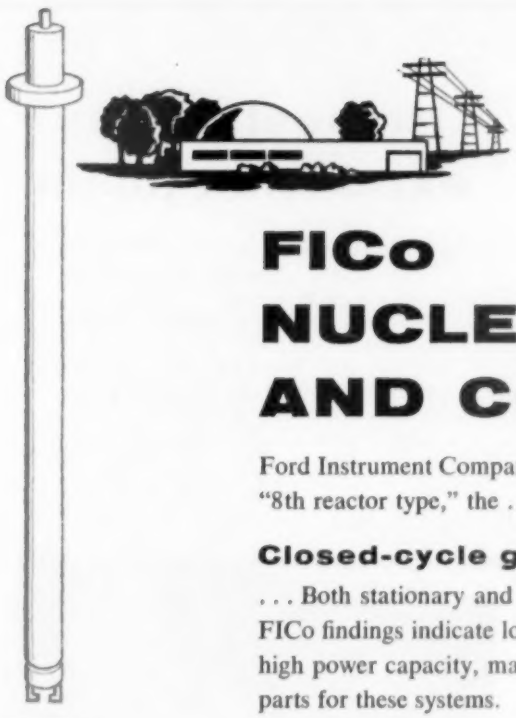

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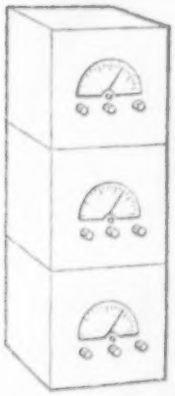

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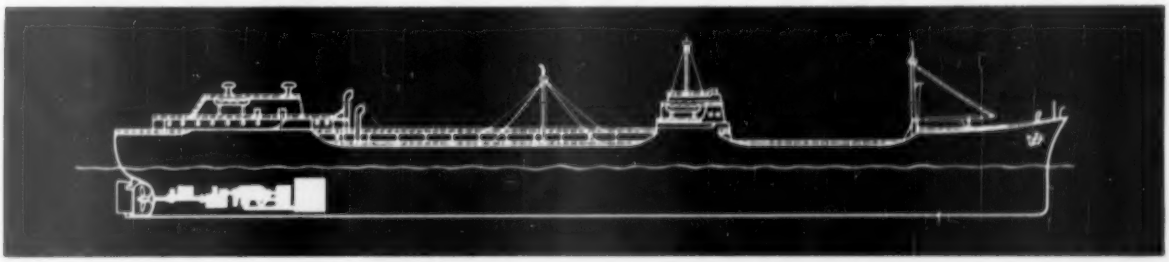

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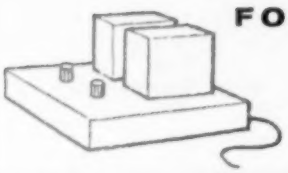

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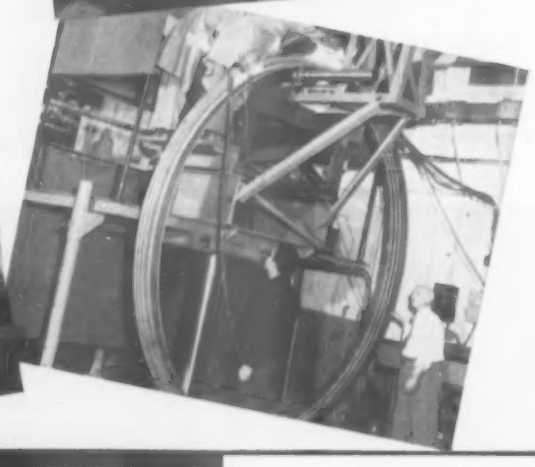

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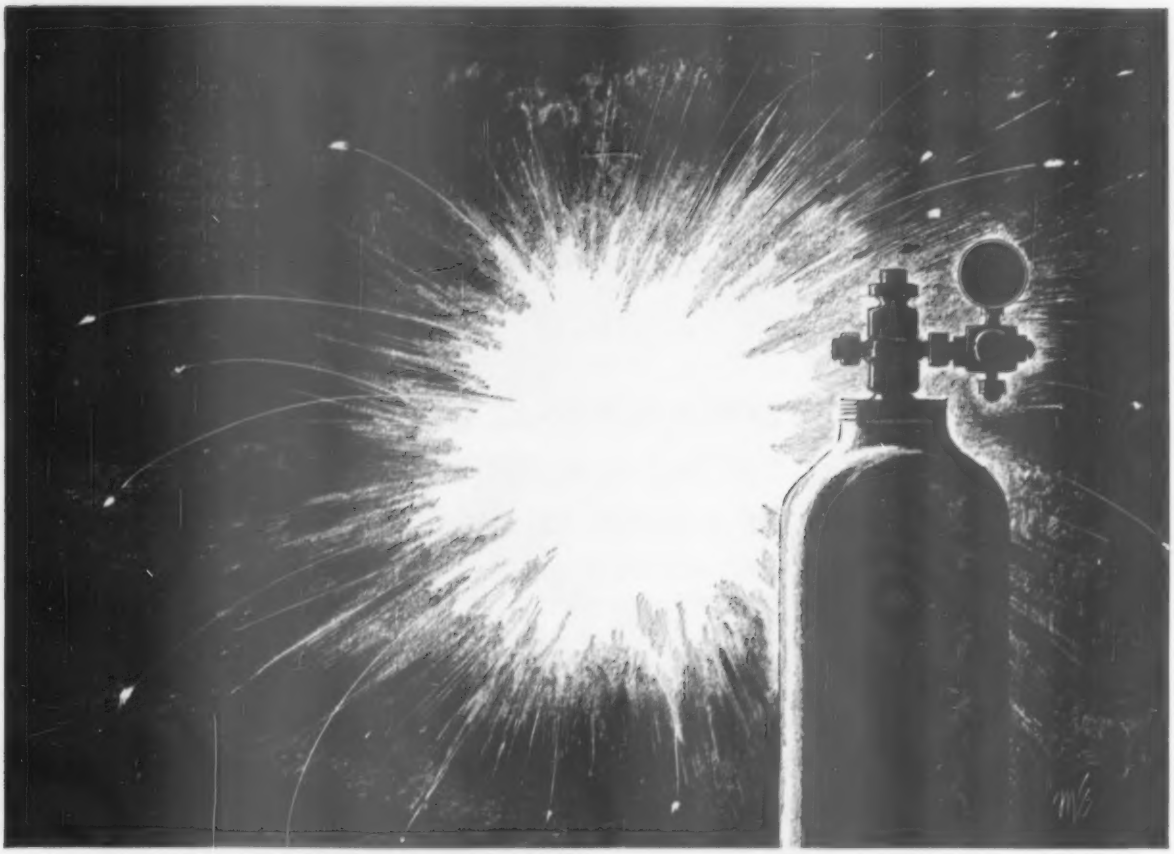

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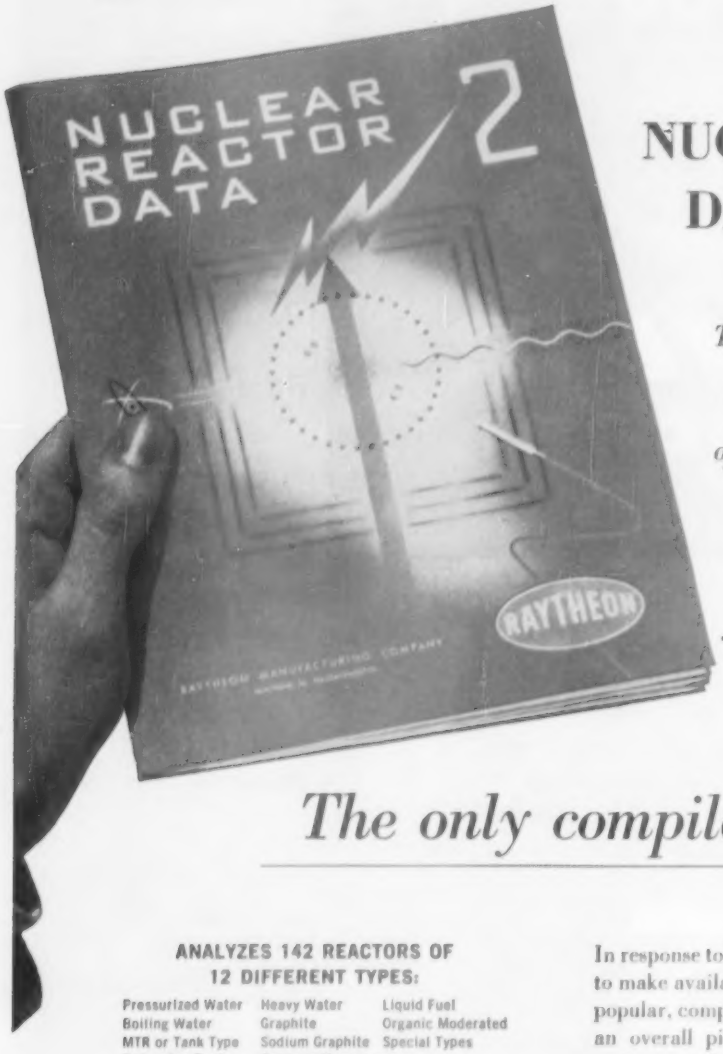

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NDA

BR II—An Engineering Test Reactor

for

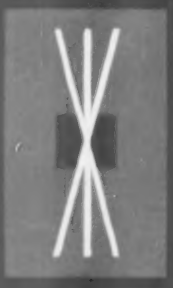
C.E.A.N. at Mol, Belgium

Centre d'Etudes pour les Applications de l'energie Nucleaire

Belgian Reactor II, an engineering test reactor of advanced concept, is scheduled for completion at Mol, Belgium, in 1959. Built and operated by Belgians in Belgium, BR II is the outgrowth of fifteen years of experimental and testing reactor development in Europe and America.

NDA has been joined by senior C.E.A.N. personnel in the detailed design, engineering, and development of BR II. NDA will continue to assist C.E.A.N. through construction and test operation in order to add U.S. experience to the abilities of C.E.A.N. and Belgian industry.

BR II



NDA NUCLEAR DEVELOPMENT CORPORATION OF AMERICA
White Plains, N. Y.

ROUNDUP of Key Developments in Atomic Energy

AEC Declassifies Its Enriched Uranium Price Schedules

Declassification of AEC price schedules for uranium and plutonium, long sought, finally arrived when President Eisenhower announced the terms and conditions on which nuclear fuel will be available to friendly nations under bilateral agreements.

The schedule of charges was announced for the benefit of foreign buyers; but that it is the same schedule as applies domestically was made clear by the President when he said, "The U. S. will make available to other nations supplies of nuclear fuel at prices identical with those charged by the AEC under our domestic nuclear power program."

He said the action taken was "designed to enable other nations or groups of nations to have firm assurance of the fuel supplies necessary to the continued operation of nuclear power installations, and thus to facilitate arrangements for financing." AEC has long been criticized here and abroad for maintaining secrecy about the price of nuclear fuels.

The prices show a reduction on the one level where a comparison can be made. Previously the only published AEC price for enriched uranium was the figure announced at the Geneva conference last year of $25 per gram of U^{235} contained in 20% enriched U. The new price is $16.12; but while the Geneva price was for uranium metal, the new charges are for UF_6. To the $16.12 must be added the cost of conversion to metal or other forms, to be borne by the user. However this is a relatively minor amount. The prices for various degrees of enrichment range from $40.50 for 1 kg of uranium enriched by 0.02% to 0.72%, to $15,361 for 1 kg of 90%—"fully enriched"—uranium (*see table p. R2*). The Geneva prices of $40/kg for natural uranium metal, and $28/lb of heavy water, remain in effect.

These are AEC sale prices. Also announced were its "buy-back" prices for fissionable material produced abroad through the use of U. S.-supplied fuel: $12/gm for plutonium metal, $15/gm for U^{235} nitrate. These prices are based, AEC carefully specified, on estimated value of these materials as reactor fuel. This should scotch the practice, rife in nuclear economics calculations during years of ignorance of AEC prices and policies, of juggling reactor operating costs on the assumption that an arbitrary military value can be set on by-product plutonium.

The buy-back prices are to be effective during the year from July 1, 1962, to June 30, 1963. Reason for this odd timing is that AEC may, under the 1954 Act, guarantee prices domestically for a maximum of seven years. It had already guaranteed the buy-back price for by-product Pu and U^{235} for the seven-year period from July 1, 1955, to June 30, 1962, and those prices remain in effect—and remain classified—for that period. AEC announced that it intends to continue to extend annually for one year the period for which guaranteed prices are established, so that the guaranty period will extend at least six years ahead at any moment.

The enriched uranium to be supplied as needed under the new schedule of charges will be taken from the 20,200 kg of U^{235} made available in 1954, 1955 and 1956 (NU, Dec. '54, 70; March '56, 17) for use in fueling research and power reactors abroad. AEC disclosed that commitments against that amount approximate 1,700 kg. The three new power bilaterals with Australia, Netherlands and Switzerland involved supplying about 1,500 kg over the next 10 years. Besides

EBWR going critical

The AEC's Experimental Boiling Water Reactor at Argonne National Laboratory is on the point of going critical. It thus becomes the first of the five reactors in AEC's five-year plan to start operating—HRT at Oak Ridge and SRE near Los Angeles are very close behind, and PWR is due to start up next summer. EBR-2 is only approaching the hardware stage (*see p. R7*). EBWR will first undergo a whole series of critical tests, lasting about a month, before being taken to power.

Third British power plant site chosen

Inkley Point near Bridgewater in Somerset (south of Cardiff across Bristol Channel) has been chosen by Britain's Central Electricity Authority as site of its third nuclear power plant (*see p. S3*). This is only about 40 miles from Berkeley where one of the first two stations will be placed.

Maritime asks bids to build gas-cycle ship engine

The Maritime Administration has asked 16 firms to bid on designing and building a closed-cycle gas-turbine engine for a Liberty ship. The plant will be tested with an oil-fired heat source, up to 12,000 shp, but designed for subsequent use with a nuclear reactor at 20,000 shp; it is intended thus to test the suitability of the closed-cycle turbine prior to the availability of the gas-cooled reactor. Several companies are now making studies of the latter for Maritime.

PRDC hearings postponed again

A second postponement has put the PRDC hearing (NU, Nov. '56, R1) off until January 8. This was ordered after a pre-hearing conference Nov. 29 at which PRDC asked the delay; the unions this time did not object.

this, the U. S. has promised to distribute 5,000 of the 20,200 kg through the newly-founded International Atomic Energy Agency, plus additional amounts matching contributions of other nations.

Another disclosure by the Commission is that it is considering arrangements to supply U^{235} in exchange for source material such as uranium ore or concentrates. Bases for such exchanges would be worked out for each case.

The six steps taken to accelerate the development of nuclear power abroad are these:

1. Extension of the schedule of domestic prices for enriched uranium to foreign users.

2. Authorization for AEC to give assurance to nations with bilaterals that the U. S. is prepared to furnish U^{235} beyond the present term of ten years.

3. Establishment of Pu and U^{233} buy-back prices.

4. Decision by AEC that, until June 30, 1963, it is ready to purchase all Pu and U^{233} produced abroad in reactors fueled with material obtained from the U. S.

5. Decision by AEC to ask legislation this year permitting it to guarantee Pu and U^{233} prices for seven years to foreign buyers, giving the latter the same assurance now offered the domestic nuclear power program.

6. Decision to consider bartering U^{235} for source material with nations having bilaterals.

Scottish Power Reactor To Hunterston, Ayrshire

Work will start next year on the third power-first nuclear station in Britain. South of Scotland Electricity Board has picked a site at Hunterston near West Kilbride in Ayrshire, 25 mi SW of Glasgow.

To cost between $84- and $112-million, the two-reactor station will have an output of 250–300 Mw. The first reactor is to be in operation in 1961, the second in 1962. Like the first two power-first stations at Berkeley and Bradwell in southern England, Calder Hall type gas-cooled reactors will be used; sea water will cool the turbines.

Operated at a very high load factor, the station will provide about a quarter of all energy required in southern Scotland, will save 1-million tons of coal annually.

Allied Chemical Picked To Build AEC U-Plant

AEC has selected General Chemical division of Allied Chemical & Dye Corp. from among seven bidders (NU, June '56, 21B; Nov., R2) to produce refined uranium salts for the Commission from crude concentrates supplied by it. Contract negotiations have already begun.

The Allied proposal, which involved lowest cost to the government, offers to supply 5,000 tons of U_3O_8 equivalent annually as highly purified UF_6. Owing to the veil of secrecy thrown, because of military significance, around production figures at the existing AEC feed materials plants at Fernald and St. Louis, it is not easy for the uninitiated to arrive at an appreciation of the magnitude of such an amount; but at AEC it is considered "a truly vast program."

The plant, to be built somewhere in the Ohio valley, is to be in operation by April 1, 1959.

Besides the Fernald plant operated for AEC by National Lead Co. and the one at St. Louis run by Mallinckrodt Chemical Works, a third, $33-million plant nearing completion is to go on stream next year at Weldon Spring near St. Louis, and will also be operated by Mallinckrodt. But all three were built with U. S. money and are government property. In line with AEC's policy of encouraging greater participation in the atomic program by industry, the new Allied plant will be the first privately-built and -owned feed materials center.

Allied will use a new process permitting it to by-pass the refining step as presently performed in AEC plants. Instead, the necessary purification will be achieved by distillation of the uranium hexafluoride.

MgF_2 Slag Treatment

Another, more modest, uranium program invitation by AEC to industry was for proposals for recovery of the 1–5% (by weight) uranium found in magnesium fluoride slag generated in the feed materials plants during reduction of UF_4 to metal. The invitation envisages sale of 4,000 tons/yr of uranium-magnesium-fluoride slag from AEC plants, processing in privately-owned facilities by an industrial contractor to recover the 40–200 tons of U it contains, and repurchase of the latter by AEC in one of a number of specified forms suitable for reintroduction into AEC production channels. The magnesium and fluorine content of the slag would remain the property of the contractor. The invitation foresees a 5-year contract, with the processor to begin operations between July 1, 1958 and July 1, 1959.

Some 75 firms have indicated interest since AEC's initial announcement in January; proposals are due by April 1, 1957. Meanwhile, to permit industry to become familiar with the processing technology involved, AEC scheduled a classified technical information meeting in St. Louis on Dec. 6–7.

Processing methods in use include carbonate leaching, phosphate precipitation, fluoride volatility, ion exchange and sulphuric acid roasting.

Enriched Uranium Prices

Following are base charges for enriched uranium as UF_6, f.o.b. Oak Ridge, varying with enrichment:

Weight fraction U^{235}	*Charge* ($/kg contained U)	($/gm U^{235} content)
.0072	40.50	5.62
.0074	42.75	5.78
.0076	45.25	5.95
.0078	47.50	6.09
.0080	50.00	6.25
.0082	52.50	6.40
.0084	55.00	6.55
.0086	57.50	6.69
.0088	60.00	6.82
.0090	62.75	6.97
.0092	65.25	7.09
.0094	67.75	7.21
.0096	70.50	7.34
.0098	73.00	7.45
.010	75.75	7.58
.011	89.00	8.09
.012	103.00	8.58
.013	117.00	9.00
.014	131.25	9.38
.015	145.50	9.70
.020	220.00	11.00
.025	297.00	11.88
.030	375.00	12.52
.035	455.00	13.00
.040	535.50	13.39
.045	616.50	13.70
.050	698.25	13.96
.060	862.50	14.38
.070	1,028.00	14.68
.080	1,195.00	14.94
.090	1,362.00	15.13
.10	1,529.00	15.29
.15	2,374.00	15.83
.20	3,223.00	16.12
.25	4,078.00	16.31
.30	4,931.00	16.44
.35	5,793.00	16.55
.40	6,654.00	16.64
.45	7,515.00	16.70
.50	8,379.00	16.76
.55	9,245.00	16.81
.60	10,111.00	16.85
.65	10,979.00	16.89
.70	11,850.00	16.93
.75	12,721.00	16.96
.80	13,596.00	17.00
.85	14,475.00	17.03
.90	15,361.00	17.07

Lucky Mc Uranium Building Wyoming Mill

AEC has authorized Lucky Mc Uranium Co. of Salt Lake City to build a $7-million U-processing mill in the Gas Hills area of Fremont county, Wyoming. Lucky Mc was the original discoverer of U ore in Wyoming. The mill, to have an ore capacity of 750–1,000 tons/day, is to be started at once for completion in a year. Perhaps the largest concentrator to use the columnar ion exchange process, it will be designed and built by Utah Construction Co., which recently acquired a controlling (two-thirds) interest in Lucky Mc.

No More Sodium Plants For Navy after Seawolf

Already eight months behind schedule and likely to be at least five more, the dockbound *Seawolf* is causing the Navy a headache. Although the second nuclear submarine's sodium-cooled reactor itself has given no difficulty, according to the Navy, highly-corrosive liquid sodium-potassium has been eating through auxiliary equipment.

On Sept. 6 the Navy admitted that "leaks have developed in the steam superheating equipment, which is not a part of the reactor proper [but] installed to obtain higher steam efficiency. The work necessary to correct this situation will extend for several weeks. The difficulty with the superheating equipment did not involve any injury to personnel or other material damage nor did it involve any nuclear radiations. So far as can be determined at the present time all materials involved were found to be in accordance with specifications." The superheaters have been sealed off and by-passed, but this will materially reduce the craft's hoped-for speed and power. Earlier this year NUCLEONICS learned there had been a minor sodium fire aboard that caused little or no damage.

Trouble is understood to lie in the NaK used (instead of mercury as in the West Milton prototype plant) in the annulus between the secondary sodium loop and the super-heater. Its function is to monitor leaks on either sodium or water-side; instead, the NaK monitor has been combining with moisture to form lye and itself eating into the piping.

On Nov. 16 a second Navy announcement said that technical studies had been underway since the superheater trouble began, "to determine the exact source and extent of the difficulty; as a result corrective action is being expedited in the hope that trials of the present plant will be possible by late December." This obviously failed to quash the possibility that the Navy might give up on the *Seawolf's* sodium plant and replace it with a *Nautilus*-type pressurized water unit. The Navy declined to comment on this, but a high AEC source told NUCLEONICS: "It's a Navy decision; my guess is that they'll try to go to sea with it if they can, but it could go either way. To yank out a lot of heat exchanger equipment is a major expense anyway." This should not be interpreted as meaning sodium cooling is a failure, he added, but merely that "we guessed wrong on the particular type of heat exchangers put in the *Seawolf*."

Nevertheless, the Navy's second statement said categorically, "The *Seawolf* reactor . . . cooled by liquid sodium is the only plant of this type installed or planned for installation in a naval vessel. The *Nautilus*-type using pressurized water is used in all other nuclear ships being built for the Navy."

Of 13 nuclear submarines authorized after *Nautilus* and *Seawolf*, Westinghouse—which built *Nautilus'* engine—has contracts for powerplants for 11; General Electric, *Seawolf* builder, for one more—water-cooled.

New England Electric approves second reactor

Construction of a 200-Mw-or-more nuclear power plant was approved by directors of the New England Electric System, which has a 30% interest in Yankee Atomic Electric Co., now starting work on a 134-Mw nuclear station at Rowe, Mass. This is the first time a U. S. utility has scheduled its second nuclear plant. Studies are already under way to determine the most appropriate reactor type, size and location for the new plant, planned to enter service by 1963 or 1964. The Rowe plant is scheduled to start up in 1960. New England president Irwin L. Moore said that "since costs of conventional fuel in this area are among the highest in the nation, we expect nuclear fuel will be competitive in New England much sooner," and added that as a result of his firm's experience with the Yankee project, "we are convinced we should start our program immediately for this second plant to maintain our leadership." Observers consider it likely the new plant will be an advanced pressurized water type, costing in the vicinity of $50-million.

Argentina buying GE research reactor

Argentina will buy a 3-Mw swimming pool from General Electric, Argentina's AEC chairman, Navy Capt. Oscar A. Quihillalt, has announced. The report to NUCLEONICS from Buenos Aires says it will be fueled by 3.6 kg enriched U supplied by the U. S., and set up at a nuclear research and training center at Pereyra Parks between the capital and La Plata.

Hungarians dynamite uranium mines

Hungary was master of her own uranium mines—apparently far richer than the West had dreamed—for just five days. Word reaching NUCLEONICS is that Hungarian forces won the U-field area at Mecsek near Pécs on Oct. 31, only to lose it again to Soviet tank divisions on Nov. 5; but that the Hungarians were able to dynamite the shafts so that it will be some time before production can be resumed. A Viennese independent daily said incomplete surveys showed U deposits sufficient to supply all Europe for 500 years, and even larger deposits are considered possible.

AEC Encourages Private Test Reactors

AEC announced it is prepared to buy time in privately-built test reactors if the price is right.

"To meet growing needs of the Commission in its reactor development program," a policy of encouragement to private industry to construct and operate "general purpose test reactors" was announced. It involves construction of further test reactors by AEC only if its needs for irradiation space cannot be met in private industry facilities, and use of AEC-owned test reactors for non-government purposes only if privately-owned facilities are not available. AEC will later invite proposals by private industry to supply irradiation services suited to its needs.

AEC's own Engineering Test Reactor, now a building adjacent to its Materials Testing Reactor at the Idaho reactor station, is scheduled to be ready for operation next summer. Privately-announced industrial test reactors include the Westinghouse Test Reactor, a General Electric unit at the firm's new Vallecitos, Calif., atomic laboratory, and a reactor to be built at Plainsboro, N. J., by Industrial Research Labs, a ten-firm combine headed by AMF Atomics (NU, Oct. '56, R5). Armour Research Foundation and Battelle Memorial Institute have already completed industrial research reactors.

Washington Report

Will the Atomic Energy Commission establish better relationships with the new Congress than it had with the last? How will the Gore plan of civilian reactor acceleration fare in that new relationship? The "202 hearings" early in the new session should tell.

Prospects are for a temper of relationship much like last year; but AEC reportedly may take a long step in the direction of the Gore plan.

AEC's standing in the last Congress probably was at an all-time low. This may have been due to election-year pressure. But the Democrats are still in control.

Key to the AEC-Congress relationship lies in the Joint Committee on Atomic Energy where the chairmanship changes. Replacing sharp-questioning Sen. Clinton P. Anderson of New Mexico will be Rep. Carl Durham of North Carolina.

Durham unquestionably has been less aggressive than Anderson. But Anderson, and Democrats Melvin Price, Albert Gore, Henry Jackson and Chet Holifield, all critics of AEC's stewardship in the past, will be back again. In fact, the only changes will be the replacements (so far unnamed) for Republicans Sen. Eugene D. Millikin, retired, and Rep. Carl Hinshaw, who died.

It is to JCAE—still arguing that it is kept in the dark too much of the time by AEC—that the Commission must report in late January. There is little doubt that one phase—nuclear power reactor development—will dominate the hearings.

Price, Anderson and Gore have promised revival of efforts to enact legislation for a U. S.-financed reactor building program. AEC Chairman Lewis L. Strauss will continue to oppose any such suggestion.

Republican members, led by Sen. Bourke B. Hickenlooper of Iowa, will probably back Strauss again. Hickenlooper says the case for a Federal reactor program never was proved. He is also opposed to Price's suggestion that the question of Federal indemnity be tied to the reactor bill.

Strauss will go all out to convince the committee that the U. S. is ahead of other countries in reactor development. On his success may hang prospects for the Federal reactor bill.

AEC is keeping up to date the list of 214 reactors in all categories Strauss issued in October. There are certain to be additions by the time he comes before the committee. Already there has been the formation of Carolina-Virginia Nuclear Power Associates. Their reactor plans may crystallize in February.

Reportedly in formation is another utility-industry group in the Texas-Southwest area, understood to be negotiating with General Electric for construction of a power reactor. There may be one or two more such groups formed by February.

Strauss will emphasize the number of concepts under study and development in addition to the reactors on the list. While advances in the field are making differentiation between types increasingly difficult, there are ten concepts now generally accepted as under study. Strauss may add to this number by February.

Further, according to current reports, he hopes to sell Congress on the idea of stepping up his budget appropriation for reactor development by $150 million for 1958 over and above the $510.3-million for 1957.

Strauss reportedly will ask also for blanket congressional approval to take one of three steps if needed to speed reactor construction:

1. Offer greater financial aid in special cases, while continuing the present course of reliance on private industry to build nuclear central stations.

2. If this doesn't work, resort to the Duquesne Light Co. Shippingport formula of joint industry-AEC financing.

3. If neither course produces the desired results, have AEC build large prototype reactors at AEC facilities.

This last would be tantamount to AEC acceptance of the Gore plan.

Main point, though, is that Strauss wants freedom for AEC to make its own decision in this matter.

D_2O Power Reactor Study at DuPont

A technological and economic feasibility study of heavy-water-moderated power reactors will be made for AEC by E. I. duPont de Nemours & Co. It will be carried out within the framework of the existing contract for operation of AEC's Savannah River plant, where duPont designed, built, and now operates five plutonium-production reactors moderated and cooled by D_2O. The study will concern design and development, and pay particular attention to the use of natural uranium fuel, AEC said, but "makes no commitment" for construction of a power reactor. DuPont has repeatedly asserted that its only interest in atomic energy, outside of operation of Savannah River for AEC, lies in radiation processing of plastics and chemicals.

During hearings on the Gore bill this summer, some experts—including Walter Zinn—had called for applying the Savannah heavy-water reactor to power production (NU, June '56, 17). Some statisticians consider the duPont study as AEC's tenth reactor concept (NU, Aug. '56, R3); an eleventh that Oak Ridge has been investigating for some time but that AEC won't say much about is the fused-salt-fueled reactor (NU, Oct. '56, R5).

Need for Standards in Nuclear Field Enumerated

To meet the problem, peculiar to nuclear systems, of reinspecting pressure vessels after operation, it has been suggested that surveillance specimens be included in the vessel at construction for removal and examination at specified intervals during the vessel life. This would ease the difficulty of inspecting reactor vessels after they become radioactive.

The suggestion was reported to the American Standards Association by Harvey A. Wagner of Detroit Edison. Other needs he pointed to in the nuclear standards field:

- Deviation from present ASME code stress allowances should be permitted for transitory high stresses of short duration in reactors, because present allowances are based on steady-state conditions and if adhered to in reactor vessel design would result in unsatisfactory design economically as well as performance-wise.
- Special standards for nuclear vessels and components also may be needed because the embrittling effect of radiation will affect stress concentrations resulting from notches, discontinuities, short-radius fillets, etc.
- New pressure piping codes to cover fluids not now covered such as lead bismuth, uranyl sulfate, uranyl phosphate; also, to take into consideration not only corrosion rates but also the possible effect of radiation on corrosion rates.
- Standards for testing buildings and exits for leak-tightness.
- Inspection procedure for cleanliness during construction, going far beyond present practice.
- Standards for recirculating air systems in nuclear plants.
- Fire fighting standards.
- Standards for stand-by equipment—pumps, auxiliary electrical supply.
- Specifications for shielding materials—lead, polyethylene, boron steel, etc.
- Procedure for testing mechanical safety devices.
- Standards for sampling and measuring radioactive waste activity, for waste collection and storage systems, and for tanks and containment facilities for handling and transporting waste.

More Opportunities In Nuclear Training

Encouraging is the word for the swelling flood of nuclear educational programs that are being announced, their variety increasing with their number (NU, Nov. '56 R8). Last month's crop:

AEC has established 150 one-year special fellowships ($1800 stipend plus tuition, dependency allowance) to encourage more students to pursue nuclear engineering and physical science studies. The program will be administered by Oak Ridge Institute of Nuclear Studies, the fourth AEC program run by ORINS.

AEC also will open unclassified facilities at Oak Ridge National Laboratory for scheduled educational tours by high school and college student groups on the first Saturday of each month. Applications should be made to ORINS.

ORINS will include a special 2-week course in basic principles of radiation chemistry for scientists and teachers, starting March 25. Applications are also open for places in AEC's fellowship program in industrial hygiene.

Queens General Hospital, Jamaica, L. I., will offer a 4-month course for 15 in medical uses of radioisotopes, starting Feb. 19 and consisting of weekly 5-hour sessions.

University of Texas Postgraduate School of Medicine, Houston, announces a 2-month course in radiological physics starting in January and July, and a one-month course in medical use of radioisotopes in March and September.

University of Chicago is instituting two new 2-year graduate courses leading to M.S. degrees in radiological physics and in health physics.

Argonne National Laboratory invites applications from U. S. faculty members and graduate students for summer or one-year science and engineering research appointments on ANL projects. Applications for summer 1957 are due Jan. 15 at ANL.

General Dynamics Corp. has made a $1-million grant to the University of California to aid its La Jolla campus to provide a graduate program in science and technology. GD's General Atomic division is a neighbor in La Jolla.

Merchant A-Ship Seen Economic in Five Years

"In about five years, nuclear propulsion will compete favorably from an economic standpoint with fossil fuel power plants in new ships operated at high speeds over long runs," according to Richard P. Godwin, project manager for AEC and the Maritime Administration on the nuclear merchant ship project.

If a second nuclear ship is undertaken in the near future, he said, the development program will have proceeded far enough to permit a "significant lowering" of costs. "Should the second ship be a supertanker, there is a very good chance that it can operate in the black from the outset, although it will not necessarily be competitive." A second ship started within two years after the first might go into commercial operation about the same time as the first, he predicted, because of the time required for the first ship in test operation, training, demonstration and foreign acceptance before it can enter commercial service.

Atomic Trailership Asked

At the same time, the operator of a trailer ferry concern asked the U. S. to build a nuclear-powered "roll-on, roll-off" ship to carry loaded truck trailers. If this were done, he said, his line would build two conventionally-powered ships with the same hull design to permit getting precisely comparable data.

Eric Rath, president of TMT Trailer Ferry, Inc., of Miami, said

the nuclear ship would cost about $40-million and the conventional ones about $12-million each. He envisages a trailership of 4,000–10,000 tons, 500–600-ft long, capable of 18–22 knots.

AEC Asks Rule Change On Data Use in Hearing

AEC has given notice of intent to introduce into its rules of practice a new rule laying down procedures for handling classified information introduced in hearing proceedings or needed to prepare for them. The rule is designed to prevent use of classified information as much as possible. The rule is being rushed through faster than usual in an effort to make it effective before the start of the Detroit fast breeder hearings (NU, Nov. '56, R1). It places an obligation on all parties to a hearing to avoid use of classified data whenever possible.

U. N. Radiation Unit Gets Fallout Reports

The United Nations' 15-country Scientific Committee on Radiation Effects concluded its second two-week session in New York (NU, April '56, 24) last month and submitted its first annual report to the General Assembly. Annexed to this were 50 reports on fallout studies from as many nations, including Russia, but these were not made public. The Committee's final report is due in July 1958; the group's next meeting will be in April 1957.

AEC License Situation

The month's activity on the AEC licensing front:

License granted: Marubeni-Iida Co., N. Y., to export to the Japan Atomic Energy Research Institute, Tokyo, an Atomics International (NAA)-built water boiler, 11/26/56

Applications received: Glenn L. Martin Co., for a critical experiment facility at Middle River, Md., 10/30/56

Curtiss-Wright Corp., for a 1-Mw swimming pool at Quehanna, Pa., 11/6/56

Aerojet-General Nucleonics, for five additional AGN-201 portable research reactors (four already requested), 11/28/56

U. S. Navy Postgraduate School to acquire and operate Aerojet-General Nucleonics' first AGN-201, at Monterey, Calif., 11/28/56

About the Industry

An unexpected baby was born into the atomic energy industry last month: Sylvania-Corning Nuclear Corporation. It is the product of the merger of all nuclear activities of Sylvania Electric Products and Corning Glass Works, each of whom will own half the new Delaware company's stock. Founded to conduct expanded research, development, and production in the nucleonics field, the objective of the new firm will be "to keep at the forefront of progress in nuclear power, especially in the 'heart' business represented by fuels, components and other materials." The firm will take over the parent companies' entire existing atomic energy businesses, "thus acquiring Sylvania's extensive background in metallurgy and Corning's leadership in ceramics," officials said. Corning is a recognized leader in development and manufacture of refractory products and ceramics as well as glass; but the fact that it had already been engaged in applying high-temperature ceramic techniques to the manufacture of nuclear fuel elements was not widely known. Sylvania has been a principal producer of slug- and plate-type reactor fuel elements for AEC, and has done advanced work in metallurgical research and fuel recovery processes.

Of Sylvania's two division facilities on Long Island—administrative headquarters and labs at Bayside and pilot production plant at Hicksville—only the latter will continue in operation as part of the new firm; the Bayside building will be taken over by Sylvania Research Laboratories. Main location of the new firm will be at extensive new facilities to be constructed at a 300-acre site soon to be chosen in New England; 50 sites have been investigated, one in suburban Boston will be picked. Among other assets of the new company is a new Sylvania contract to fabricate 40 MTR-type enriched U-Al alloy fuel elements for Canada's new swimming pool "swing" reactor nearing completion at Chalk River.

■

Martin International has been founded by Glenn L. Martin Co. as a wholly-owned subsidiary to explore and develop world markets for nuclear-powered electric generating systems. Martin vice president for procurement George B. Shaw will head the new company. Its program will concentrate on areas where power-hungry countries are ready to commit themselves to a program of nuclear development.

●

A new Nuclear Power Equipment division was set up last month at Kieley & Mueller of Middletown, N. Y., manufacturer of automatic control valves, power and steam specialty equipment. The new division starts life with $750,000 in valve contracts, will build ultra-high-temperature, bellows-sealed control valves with self-contained control systems for a nuclear propulsion development facility.

●

Great Lakes Carbon Corp. of New York has joined with Britain's Nuclear Power Plant Co. in setting up a new U. K. firm, Anglo Great Lakes Corp., to build and operate an $18-million nuclear graphite plant to be completed by 1958. Annual production will be 10,000 tons. A 78-acre site at Newburn Hough on the Tyne has been selected. This will be Britain's second nuclear graphite plant (Acheson Electrodes Co. collaborating with Union Carbide Corp. is running the other); the move will thus eliminate a threatened graphite bottleneck in the British nuclear power program.

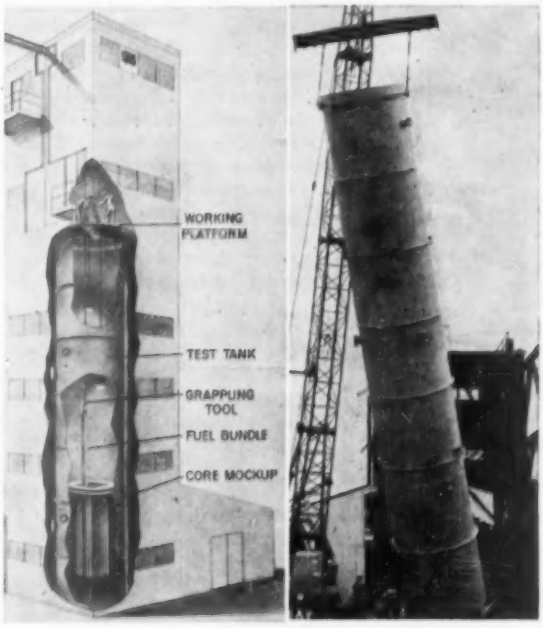
Reactor News

FOOD CENTER TO BE IN CALIFORNIA

The long-awaited site announcement on the Army's food irradiation center came last month: Sharpe General Depot at Stockton, Calif., 60 mi W of San Francisco, has been chosen. Still to be decided is the manufacturer for the $3-million Food Irradiation Reactor the AEC will build there for the Army Quartermaster Corps: 11 firms bid (NU, Oct. '56, R5), and four are said to be still in the running. Work is to start by end of June, and the center is to be in operation by late 1958. Other facilities of the center, costing an estimated $4.5-million, will include an accelerator, labs, offices, and processing and storage areas. Primary mission of the center at the outset will be to develop methods of utilizing radiation to preserve foods and to assess their economic feasibility. The processing area will be designed with a high degree of flexibility to accommodate a large variety of products and to permit modifications in processing lines as improvements are made.

GE BUILDS REFUELING TEST TOWER

Because General Electric decided that "manual refueling of the Dresden station was the safest and surest method," it is building a special test facility at San Jose to develop



and prove procedures and equipment for refueling the 180-Mw nuclear station the firm is building near Chicago for Commonwealth Edison. Housed in a steel tower 86 ft high, it will center around an all-welded, 14-ton steel tank 56 ft high × 8 ft dia simulating the pressure vessel of a large boiling-water reactor. A core mock-up will be installed at the bottom of the water-filled tank, and technicians will work from a platform above it, inserting and removing dummy fuel elements with long-handled grappling hooks. An underwater TV camera close to the "core" will enable them to watch their efforts at close range; periscopes are also being provided. The facility is scheduled to be in operation this month.

ANN ARBOR REACTOR DEDICATED

Michigan University's Ford Nuclear Reactor, a 1-Mw swimming pool built with a $1-million gift from the Ford Motor Co. Fund, was officially dedicated—but not started up—with a ceremony on the University's new north campus last month. When it goes into operation later this month, it will be the country's third, and the most powerful, college reactor. The pool, with 6½-ft high-density concrete walls containing 41,000 gal water, adjoins the $2-million Phoenix Memorial laboratory for radiation research, already in use (NU, Nov. '55, 76). Six lb U^{235} in 23 MTR-type fuel elements form the core, 21 ft under water and surrounded by 12½ tons of graphite reflector; peak flux is 10^{13}. Twelve beam ports and a rabbit system are provided in the Babcock & Wilcox-built facility. AEC inspectors are now making their final check, last requirement before start-up.

. . . AND NAVAL RESEARCH REACTOR CRITICAL

Three days after getting its operating license from AEC, the Naval Research Laboratory in Washington, D. C., started up its swimming pool. Critical experiments and initial calibration will take until mid-December, after which the reactor will go into operation at 100 kw; higher power levels may be authorized later. More than three years in design and construction, it—like the Ann Arbor pool—cost $1-million; likewise, it also has large hot cell facilities adjoining. As forecast, (NU, Aug. '56, 53) 3.4 kg contained U^{235} was the critical mass for the cold, clean, totally water-reflected core. Seven beam ports and a thermal column are provided at one end of the pool for neutron beam work, as well as a rabbit system for short-lived isotopes. The reactor may be used by any of NRL's 14 scientific divisions and by other groups in the capital area, and will serve as a training tool in NRL's reactor engineering course.

CANADA'S FIRST PRIVATE REACTOR TO AMF

AMF Atomics (Canada) subsidiary of AMF Co. of New York will design and build Canada's first privately-owned research reactor, for McMaster University, Hamilton, Ont. Although built on the campus of the university's science school, the pool reactor will serve as an industrial research tool as well as a training aid. It will be financed by the government, Ontario Hydro Power, and several Ontario industries.

FERGUSON PICKED FOR EBR-2

H. K. Ferguson Co. of Cleveland was selected by Argonne National Laboratory as architect-engineer for the design of Experimental Breeder Reactor No. 2, fifth and last unit in AEC's five-year program of reactor development. The 20-Mw fast breeder will be built at AEC's Idaho testing station, near EBR-1.

ARGONNE INVENTS 'SLOW-FAST' REACTOR

A revolutionary design is embodied in Argonne's latest zero power reactor, ZPR-3, now in operation. A "reactor within a reactor," ZPR-3 consists of a 5-ft dia steel tank in the center of which is a 2-ft' fast core of 49 enriched-U fuel assemblies; surrounding this is a slow section of normal and enriched fuel elements immersed in water. Both cores are chain-reacting. The design is said to utilize the best features of both fast and thermal reactors—the safety and ease of control of the latter, the superior nuclear properties of the former. Connecting the two systems will make it possible to study the nuclear physics of fast reactors without being troubled by their control difficulties.

TABLE OF FRENCH REACTORS

[prepared with the assistance of French A.E.C. at Paris

Function	Startup	Moderator	Coolant	Fuel	Location	Power: Heat	Power: Elec.	Cost ($1 × 10^6)	Flux (n/cm²/sec)
ZOE Research	1948	D_2O	None	3 T sintered UO_2	Châtillon	5 kw	0	?	?
ZOE (modified)	1953	D_2O	D_2O	2 T natural U	"	150 kw	0	?	10^{13}
P-2 (or EL-2) Research	1952	D_2O	N_2, later CO_2 at 10 atm	3 T natural U	Saclay	2.5 Mw	0	6	10^{13}
AQUILON Lattice studies	Aug '56	D_2O or H_2O	None	Variety of fuel types & arrangements	Saclay	1 w	0	0.5	?
EL-3 Materials research	1957	D_2O	D_2O	Lightly enriched U	Saclay	10–15 Mw	0	10	10^{14}
Swimming Pool #1 Shielding research & training	1958	H_2O	H_2O	About 5 kg U^{235} contained in enriched U at 20%	Grenoble	1 Mw	0	?	10^{13}
Swimming Pool #2 Shielding research	1958	H_2O	H_2O	Same as above	Châtillon or Saclay	1 Mw	0	?	10^{13}
MINERVE Reactivity studies	1958	H_2O, perhaps BeO	None	About 3 kg of U^{235} contained in highly enriched U	Châtillon	1 w	0	?	?
PROSERPINE Homogeneous reactor for research	1957	H_2O	H_2O	Pu sulfate solution (few hundred grams)	Saclay	1 w	0	?	?
REACTEUR MARIN (prototype reactor for naval propulsion. Characteristics unavailable)									
PILE CHAUDE (prototype reactor of weak power functioning at "very high temperature." Not for electricity production. Characteristics unavailable.)									
G-1 Pu production	Jan. '56	graphite	air	100 T natural U	Marcoule	40 Mw	5.75 Mw*	20	5.5×10^{13}
G-2 Pu production & power	1957	graphite	CO_2 at 15 atm	100 T natural U	Marcoule	150 Mw	30 Mw**	30	2×10^{13}
G-3 Pu production & power	1958	graphite	CO_2 at 15 atm	100 T natural U	Marcoule	150 Mw	30 Mw**	30	2×10^{13}
EDF-1 Power & Pu production	1959	graphite	CO_2 at 25 atm	130 T natural U	Avoine	300 Mw	60 Mw**	40 (estimate)	4×10^{13}

* Only experimental production. The net balance is negative.
** Net balance.
NOTE: All these reactors use thermal neutrons.

Report from France

PARIS

Perhaps the most interesting characteristic of the French atomic energy program today is that France, in the face of certain American and British contrary opinions, continues to put its faith in the development of plutonium as compared with enriched U^{235}. Admittedly when the Commissariat à l'Energie Atomique in 1952 embarked on its initial five-year plan, the choice between Pu and U^{235} was somewhat academic. France, with its limited resources, understandably opted for Pu. As a result the only important exception to French independence in its atomic program today is that it does not separate U^{235} on an industrial scale, though research along this line is being carried out.

French CEA officials don't for a moment deny considerable interest in using U^{235} as fissionable material in prototypes for more compact reactors. Last June, CEA signed a bilateral with the U. S. covering some 40 kg of enriched U which the Commissariat will use to meet immediate needs. But French atomic scientists nevertheless think Pu is the fissionable material of the future, and CEA feels it must make its technical bid toward this end. The Commissariat thinks that the thorium-U^{233} cycle, while very promising, will necessarily come about more slowly.

The main feat of France's first five-year plan, which will draw to a close next year, is easily the construction of the plutonium-producing center at Marcoule. The $20-million G-1, which went critical last January, generates 40 Mw of heat and produces 15 kg of Pu annually. (NU, Feb. '56, 15; April, 22).

The second Marcoule reactor, G-2, is scheduled to start up next year; the third, G-3, in 1958. They will be identical and are being built at an estimated cost of $30 million each. Technically, G-2 and G-3 are comparable to the dual-purpose British reactors at Calder Hall. Like G-1, G-2 and G-3 will use 100 tons of natural U as fuel and graphite as moderator. But whereas G-1 uses air as coolant, G-2 and G-3 will use CO_2 at 15 atm.

The French have built up a certain amount of experience with this type of coolant. The research reactor P-2, built in 1952 at a cost of $6 million and installed at the CEA's atomic research center at Saclay, 12 mi S of Paris, was the first and, until very recently, the only reactor in the world to use compressed gas as a coolant. P-2, incidentally, has been used for a variety of research purposes including the study of radiation damage on materials and neutron research. P-2 also produces radioisotopes and a small quantity of Pu.

Marcoule, which covers 600 acres on the banks of the Rhône, is also noteworthy in that it has brought together large industrial groupings for the construction of the three piles. G-1 was built by four big French firms: the Societé des Forges et Ateliers du Creusot, Societé Alsacienne de Constructions Mécaniques, Societé Alsthom, and Societé Rateau. A $15-million-plus Pu extraction plant also is going up on the site, and should be in operation next

year. This work is being done by the chemical firm Saint-Gobain.

The first real—i.e. power only—nuclear central station, EDF-1, is being designed and built jointly by the Commissariat and the State-owned utility Electricité de France for an estimated $40 million. Ground has been broken on the EDF-1 site at Avoine in the Loire Valley. EDF-1 is slated to start up in 1959, producing 60 Mw net of electricity. Present French plans now envisage that EDF-1 will be followed by a new station every year, instead of one every 18 months as originally planned. The goal is to double installed capacity every three years. This will be achieved thanks to the increasing unit power of future stations. As a result, it is estimated that by 1970 France will have about 800 Mw of "atomic electricity."

While EDF-1 will use natural U as fuel, graphite as moderator, and CO_2 at 25 atm as coolant, this arrangement will not necessarily be followed in future EDF installations. Reactor characteristics will vary according to what the French learn from the operation of several prototype reactors now being built or studied both at home and abroad. CEA scientists admit that some of the future EDF reactors may use slightly enriched fuel. Among other systems of cooling, the circulation of liquid sodium—already slated to be used in the U. S. AEC's sodium graphite reactor and in Britain's fast reactor at Dounreay—may be attempted by the French as well.

At the moment, French experts are putting the finishing touches on the nation's second atomic five-year plan which will go into effect at the end of next year, although 10-billion francs earmarked for it will actually be spent during 1957. Included are many of the prototype and research reactors detailed in the facing table, as well as additional EDF power reactors.

According to Georges Guille, French State Secretary for Atomic Affairs, the new five-year program probably will involve expenditure of 200–300 billion francs. The program will go before the National Assembly early next year. By contrast, France by the end of 1957 will have invested 150 billion francs in its atomic future since Gen. de Gaulle's government, back in 1945, hopefully set up the CEA with a small grant of 500 million francs.

In addition to the problems of achieving the highest possible burnup and improving thermodynamic yield, the French, like everyone else, are concerned with the cost price of spent fuel reprocessing. The CEA's position seems to be that during the present transitional period in which the nature, form and residual enrichment of the irradiated fuel will be subject to innumerable variations, reprocessing units will have to be particularly flexible, numerous and diversified.

Just where in France the government plans to build most of its atomic power centers is not as yet known. EDF-2 will be built alongside EDF-1 at Avoine, that much has been decided. But beyond that, it is generally believed Electricité de France will continue to locate most of its power plants in regions where thermal energy is high in cost and hard to come by.

Carrying out a program of installing power reactors is not preventing France—though her means are much more modest than those

of the U. S. and Britain—from undertaking studies on various kinds of prototype reactors. The Réacteur Marin, whose characteristics are as yet unavailable, is oriented toward maritime propulsion. The project Pile Chaude (high temperature reactor), about which CEA says only that it is of weak power and functions at "very high temperature," may have certain aeronautical applications. Cooperating on this is SNECMA, the big State-owned aircraft engine firm (NU, May '56, 22).

CEA's research and prototype studies are carried out by some 6,000 employes (of whom 1,200 are nuclear engineers) at the Commissariat's main centers at Châtillon and Saclay near Paris, as well as at the new CEA center at Grenoble. CEA's important $10 million experimental pile EL-3, a high-flux reactor, will make extensive studies of radiation damage on materials. The slightly-enriched U fuel element is being supplied by the British AEA while the U. S. is supplying D_2O for use as moderator and coolant. Present French plans apparently do not include construction of a breeder reactor, though such a project eventually will be taken up.

The relative independence of the French atomic program, which the French understandably want to maintain, stems in large part from CEA's ability to draw upon French resources. For example, uranium mining in metropolitan France and extraction of thorium on the French island of Madagascar continue to develop rapidly and have made France the No. 1 uranium producer in continental western Europe. Production figures are still unavailable, but France easily covers its program needs and then some.

Swedish Government, Industry Vying in A-Power

The Swedish government is putting pressure on the State-dominated Atomic Energy Company to build a commercial prototype power reactor, and is simultaneously supporting private industries' plans to realize their own reactor designs, about six months to a year behind. At this point, according to reports to NUCLEONICS from Stockholm, it seems certain that private industry will get Sweden's second reactor contract, and that the time lag is strictly a matter of government prestige, not a manoeuver to push industry out.

This is the upshot of recommendations made last month by the government's advisory Atomic Energy Delegation regarding the new budget. This would contain 83.5-million kronor—$16.7-million—for the Atomic Energy Company—$3-million of it to be tacked on to the current fiscal '57 budget of $7.3-million granted earlier, and the other $13.7-million for fiscal '58. In addition, the Company would get a green light for an immediate start on building an $8-million prototype space-heat reactor, Sweden's first commercial reactor, in the Stockholm suburb of Färsta. The green light is in the form of a $1.5-million purchase authorization for making a start. The new budget also would grant $2-million to the State Power Board to order the nation's second commercial reactor for a heating plant at Västerås, but only when the Färsta reactor is well under way.

Sweden's energy position, perhaps unique in Europe, makes her future even more dependent on atomic energy than Britain's. She has no domestic oil at all, practically no coal, only uneconomic shale oil and peat, and her hydro potential is about fully exploited. The vital importance of reactor development to Sweden, therefore, is difficult to overestimate.

Like Italy (NU, Oct. '56, R9) and other countries (including the U. S. with its Gore bill debate), Sweden has been undergoing a government vs industry dogfight over who is to develop nuclear power. This summer the spectre of a totally-nationalized nuclear power industry was dispelled, and the long-term outlook for foreign reactor manufacturers in the Swedish market brightened. For the first time since the Swedish atomic energy program got underway, there is a law and a protocol clearly defining the rights and limits of industry in reactor development. The limits for government are less clear.

The law became effective July 1. Its passage had been hastened when the Company asked more capital for new research facilities in connection with the country's second reactor (the high-powered ORR-type materials testing unit since bought in the U. S. from ACF Industries). The request for funds came in October 1955 when the Company's board of directors increased share capital from $700,000 to $2.8-million. (The government owns ⅓ths of share capital, industry ⅔ths. The government provides all operating funds: $12.3-million total from 1947 through June 1956, compared with the $7.3-million originally voted for the 1956–57 fiscal year alone.) Both industry and government sought a clarifying law before putting up the money. A storm followed when a government study committee brought in a report calling for a law that would have totally nationalized the atomic industry. Private industry, which had cooperated with government since 1947, felt itself in danger of being written out of the country's nuclear program; the largest electrical equipment manufacturer, Asea threatened to move its development department abroad. (Asea has production facilities and trained specialists the government itself lacks.)

The law as passed mentioned no government monopoly, made construction and operation of all reactors subject to government license. Manufacture of fuel and fuel elements remains Company domain—i.e., under government control. An "Atomic Energy Delegation" in the Commerce Ministry will review license applications as well as requests from the Company and research institutions for state funds; an advisory board for the government, it will serve also as contact with international nuclear groups such as CERN. The law makes no mention of heavy water, which remains in the private domain (Asea is pushing pilot tests on an economic method).

The protocol signed June 27 by industry and government stockholders in the Company aims at defining their respective roles, on the basis of the new law. Yet it is a source of unclarity in industry-government relations. It says industry may "compete openly" in tendering designs for delivery in Sweden, and may export reactors and components freely. The catch is that for three years, design and construction of prototype reactors will be a virtual monopoly of the Company (a compromise between those who wanted complete government control of development work and those who wanted no controls except on safety). Nothing says the government may not extend the three-year period. So industry's reactor development plans are clearly subordinated to the Company's.

World News

Second Harwell Set for Dorset

Plans for construction of a new British reactor research center at Winfrith near Dorchester (NU, April '56, 23) have received local approval, and ministerial approval is expected to follow shortly. About 2,000—half Harwell's force—will be employed eventually at Winfrith Heath.

More British Firms Enter Field

A fifth British industrial consortium is to be announced shortly, NUCLEONICS learns; it is to include Richardsons Westgarth & Co. (NU, May '56, 22) and Crompton Parkinson; also associated may be Rolls-Royce (NU, April '56, 23) and DeHavilland (NU, Nov. '56, R11). At the same time, Hawker Siddeley, the airplane manufacturer, has announced it is working on small liquid-metal-fuel reactors for package, propulsion, and process-heat uses.

Dido Goes Critical

Britain's first large heavy-water reactor and the most powerful research reactor in western Europe, Dido went critical at Harwell on Nov. 7 and was formally opened Nov. 21. At full power, 10 Mw heat, its 10^{14} neutron flux is 50 times that of Bepo, will permit carrying out of materials testing work that until now had to be taken to Canada's NRX. Dido uses highly-enriched U fuel.

Other British Developments

Competing against U. S. firms, Isotope Developments Ltd. of London has won a consultantship to Landis & Gyr A. G. of Switzerland, to recommend and supply all instrumentation for P-34, the high-powered second Swiss research reactor (NU, June '56, 19B). . . . The first routine check-up of lower fuel elements of the No. 1 reactor at Calder Hall was carried out in late November, first of several routine checks during the six-month commissioning period of the two reactors at Calder A station. Main purpose was to inspect behavior of lowest of six fuel elements in each channel, which must support weight of five elements resting on it in the channel. The inspection will, it's hoped, permit improvements in core design. Likewise, although this check necessitates shutdown from half a day to several days because Calder fuel element charging and discharging equipment is not fully automatic, later Calder-type stations will have fully automatic fuel-handling machinery and similar checks will not involve shutdown. . . . What is claimed to be the world's first commercial isotope-separation column is now producing boron-10 at 20th Century Electronics' works at Croydon, Surrey. The 30-ft high column makes about a pint of boron trifluoride etherate a month at over 99% enrichment. Larger columns are planned.

Nuclear Power for South Italy

Italy's two big government industrial groups, IRI and ENI, will jointly build a 100-Mw nuclear power station in southern Italy, the Cabinet has decided. The power will be used by Finelettrica, an IRI-financed power company. Fuel will be imported from Britain or the U. S., but the two groups will set up between them a company to prospect for nuclear ores to fuel subsequent stations. Earlier, ENI had announced it would spend $35 million in the next four years for nuclear research and development. Also, it has been decided to set up a Sicilian Center for Nuclear Physics; $250,000 has been appropriated for it.

Germany Plans Atomic Locomotive

The German Federal Railways plans construction of a nuclear locomotive smaller and lighter than those discussed in the U. S. Instead of a 14-axle, 330-ton engine with 6,900 hp output, the German plan is for an 8-axle, 175-ton, 5,916 hp locomotive with a gas-cooled reactor. It would cost 2-million marks ($500,000) to build and 2 marks/km (5¢ mi) to operate at 200,000 km/yr service—less than a steam engine, slightly higher than an electric one.

Systematization in Japan

Feeling that research on atomic power generation has not been adequately systematized, the Central Research Institute of the Electric Power Industry, the Federation of Electric Power Companies, and nine utilities have set up in Tokyo the Atomic Power Systematization Committee. It will seek closer coordination of research.

Delay in Denmark

Work at the nuclear research center site at Risø is being accelerated; the boiler house is to be pushed to completion by Dec. 15 to provide heat and steam permitting further work to continue through the winter. Nevertheless, even though the zero-power Atomics International water boiler will probably be installed in March, the 5-Mw Foster Wheeler tank-type unit cannot be completed until May, and will not arrive on site until June. Installation will require another four months. The hope now is for opening of the research center in November, some eight months past original plans.

Montreal Builder Gets Indian Job

Foundation Co. of Canada Ltd., Montreal, has been awarded a contract by Atomic Energy of Canada to erect India's second research reactor, the Canada-India Reactor for which Canada is contributing more than half the cost (NU, '56, 23).

Power Plans in Czechoslovakia

A 150-Mw power plant is planned during the current (1956–60) five-year plan. It will be CO_2-cooled, burn 1 kg of domestically-mined uranium a day. Site will be near the Ziar na Hronu aluminum combine.

New Research Programs in Australia

Research project contracts let by the Australian AEC to universities include these: Melbourne Univ.—chemical and metallurgical research on refractory materials suitable for high-temperature reactor fuels; Sydney Univ.—chemical engineering work on dispersions and slurries of high-density materials, and gas turbine and heat transfer problems; Adelaide Univ.—heat transfer to boiling liquids; Univ. of Tasmania—development of large neutron counters; New South Wales Univ. of Technology—boiling sodium metal, methods of extracting purified uranium nitrate from ores, construction of a reactor simulator.

Uranium Finds Around the World

Promising deposits of betafite with a very high uranium oxide content have been found in the Tambani area of Nyasaland's southern province. . . . Pitchblende has been found in Southern Rhodesia, and Britain has agreed to buy any radioactive minerals found in the country at "a very advantageous price." Niobium and thorium have also been found in central Northern Rhodesia. . . . Inter-American Uranium Corp. with $3-million capital has been founded in Havana to continue explorations pursued for a year in Pinar del Río province of western Cuba. . . . Small U finds are reported in New Zealand.

News in Brief

D_2O Plant Bought by Canadian Firm

Consolidated Mining and Smelting Co. has bought from the U. S. government, for an undisclosed price, the heavy water plant located at its chemical fertilizer operation at Trail, B. C. The U. S. AEC, for whom Cominco had operated the plant, closed it down early this year because it was too costly. Although D_2O production is discontinued, some of the equipment will be adapted for hydrogen plant use. The facility, known as Project 9, was built in 1942–43 for $2–3-million as part of the Manhattan District bomb effort.

Yankee Doubles Capitalization

A second $1-million is being raised by Yankee Atomic Electric Co., which is seeking State approval to sell stock and notes to its 11 member utilities. The additional funds in this interim financing are for carrying forward the program to build a nuclear power station at Rowe, Mass. Balance of the total $35-million capital expenses of the project will be raised by later issues.

Strontium-90 Study Extended

AEC has extended its contract with Isotopes, Inc., for determination of Sr^{90} concentration in bone, vegetation, rainwater, and gummed paper. The sampling is part of AEC's world-wide atomic fallout monitoring system, and is designed to yield statistics on distribution of bomb-produced isotopes.

SPERT-3 Contract to Hardeman

Paul Hardeman Inc. of Los Angeles was apparent low bidder at $1,580,000 for a contract to build SPERT-3 at the Idaho reactor testing station (NU, Oct. '56, R12). Nine firms bid.

Lithium Institute Founded

The three major U. S. Li producers—American Potash & Chemical Corp., Foote Mineral Co., and Lithium Corp. of America—last month set up the American Lithium Institute, Inc., to conduct research on the light metal and its compounds. Offices and a library will be maintained in Princeton, N. J. Research projects will be assigned colleges and research institutions.

New Tool for Working Radioactive Metal

Rolling mills for fabricating fuel elements of plutonium or other hazardous materials—U, Zr, Be, Th—have been placed on the market by Stanat Mills. Similar to, but larger than the one in Babcock & Wilcox's Lynchburg plant (NU, Sept. '56, R8), the mill is said to be the first based entirely on remote control operation within a glove box. Two units have been delivered to Argonne National Laboratory for installation inside a CR-39 allyl polymer transparent hood containing a helium atmosphere at $-\frac{1}{2}$ to $-1\frac{1}{2}$ psi; among other things, they will make fuel elements for fast breeders. The mill can roll both flat stock, to 20 ft long and 0.003 in. sheet, and shapes: rounds, squares, ovals. Cost is $50,000, plus about $5,000 for the hood and $15,000 for remote control and other electrical equipment.

$2-Million Fire at Paducah

AEC's worst fire to date started when a pump motor at the Paducah, Ky., gaseous diffusion plant overheated, igniting lube oil; fire spread to the roof. The building involved was not a process building but contained auxiliary equipment. No U^{235} capacity was lost—operations continued uninterrupted thanks to a makeshift arrangement. One man was slightly injured.

Franklin, Mellon Institutes Expand

Establishment of a separate nuclear engineering division by the Franklin Institute's research and development laboratories was announced last month. The Philadelphia Institute has been engaged in nuclear research for several years, felt its activities in the field had grown rapidly enough to warrant a separate division. Thirty specialists at Franklin are providing technical and design studies on PWR, the Dresden boiling water reactor, and the Detroit fast breeder. Earlier, Mellon Institute in Pittsburgh announced plans to build a $1-million lab to house its new radiation research department (NU, Sept. '56, R12). The lab, to be built on a 125-acre tract near Export, Pa., 20 mi E of Pittsburgh, will house a 3-Mev Van de Graaff, is to be completed by fall.

To Study Radiation Effects on Plastics

The American Society for Testing Materials has set up a subcommittee to study effects of nuclear and high energy radiation on properties of plastics and electrical insulation. Chairman D. S. Ballantine of Brookhaven National Laboratory emphasizes the need for standardization in the field of radiation effects.

ORINS Gets 38 Acres

Until Oak Ridge Institute of Nuclear Studies was given a deed last month to 38 acres of land in Oak Ridge (adjacent to the new downtown shopping center), on the occasion of its tenth anniversary, the only object ORINS owned was its corporation seal. All its buildings and equipment belong to AEC. The plot will provide ORINS a site for a $3.25-million home of its own. Construction is contingent on securing funds through grants or gifts from foundations, other non-government sources.

AEC Attache Program Moves Ahead

As foretold (NU, Sept. '56, R1), AEC is setting up liaison offices abroad, and Amasa S. Bishop has assumed the first post, in Paris. Edward L. Brady, formerly with KAPL in Schenectady, is opening the London office. AEC representatives abroad will "assist in scientific and technical aspects of the rapidly expanding work related to the U. S. program . . . including liaison with the atomic energy authorities and technical staffs of the country to which they are assigned and expediting the day-to-day scientific and technical problems growing out of the U. S. bilaterals."

Van de Graaffs an Export Item

High Voltage Engineering Corp. has sold two 2-Mev Van de Graaff accelerators abroad, one to Portugal's AEC, the other to Japan's Atomic Research Institute.

U. S. Runs Panels for Belgian Industry

AEC and the Atomic Industrial Forum handled the two ends of a full week of power reactor discussions held in Brussels and at the Belgian nuclear research center at Mol for Belgian industry and government. The Forum staged a three-day, unclassified conference in Brussels, at which leaders of U. S. reactor-building firms spoke. The following two days, AEC officials delivered classified talks at Mol. Belgium requested the meeting.

IBM Building Super-Computer for LASL

Development of a computer from 100 to 200 times as fast as any comparable general-purpose computer has been begun by IBM for Los Alamos Scientific Laboratory. Called Stretch, it will do 10^{15} arithmetical operations in a day.

RADIATION

no matter what its source

can **BEST** be analyzed

using the unmatched

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PRECISION

VERSATILITY

EFFICIENCY

RELIABILITY

of the

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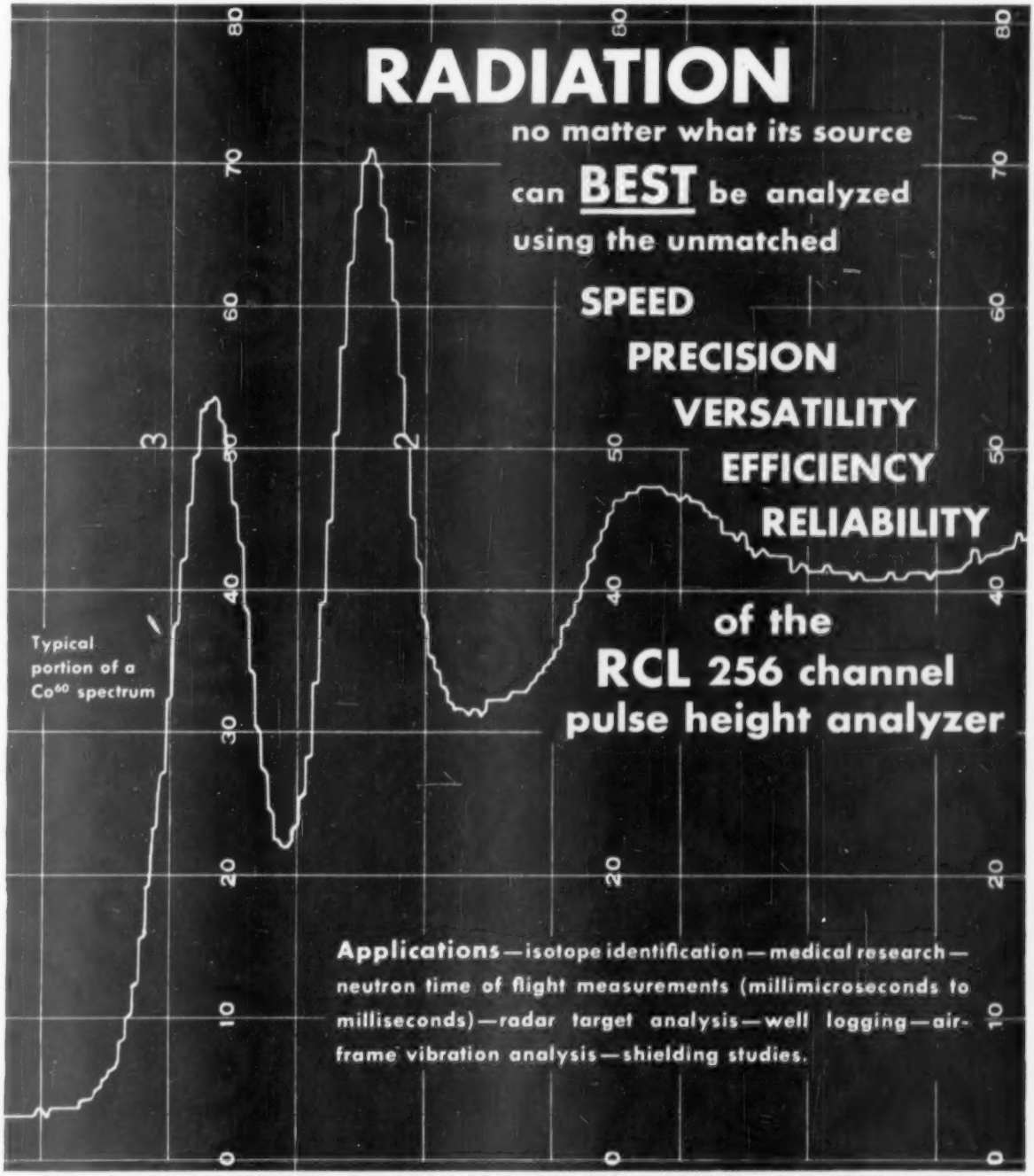

Applications—isotope identification—medical research—neutron time of flight measurements (millimicroseconds to milliseconds)—radar target analysis—well logging—airframe vibration analysis—shielding studies.

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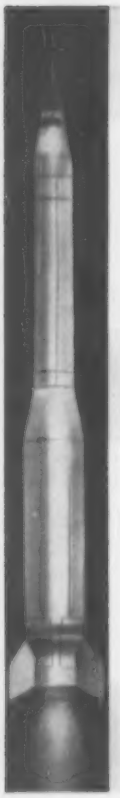

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Point 2 is part of *our* responsibility. This is the Martin-U.S. Air Force TITAN program... one of the most advanced and critically important development projects in America today... an Inter-Continental Ballistic Missile conceived in peace and dedicated to the proposition that no aggressor shall ever take the life of this country.

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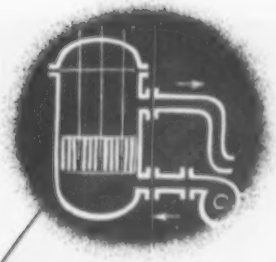
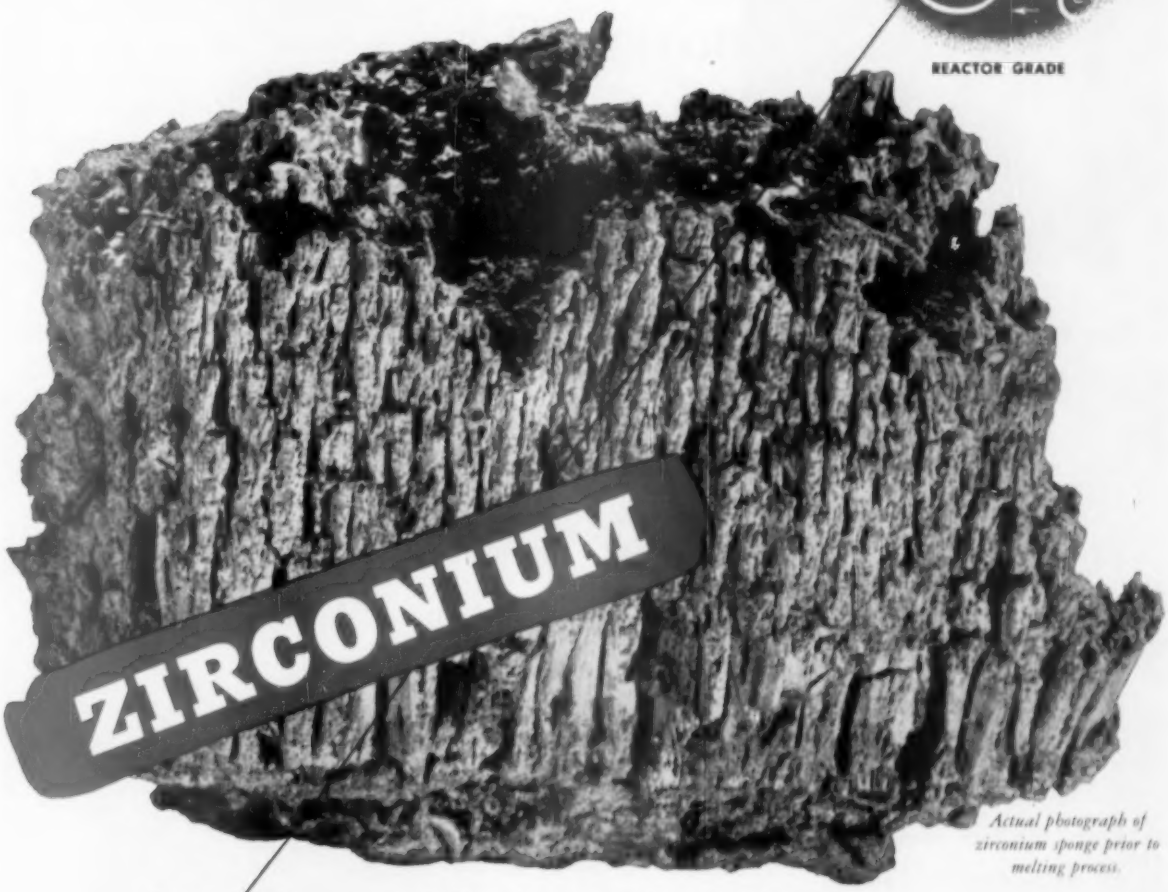
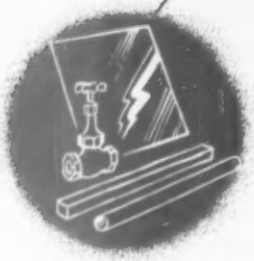


REACTOR GRADE



Actual photograph of zirconium sponge prior to melting process.

...from the world's largest producer



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PROVEN METHODS—in production *now*. CARBORUNDUM METALS' hafnium separation, metal reduction and high temperature vacuum distillation processes assure zirconium sponge metal to meet the most exacting requirements. These methods are the result of many years of research and development.

PROVEN QUALITY—Soft, ductile, low-chloride zirconium sponge has already been delivered in quantity, meeting rigorous spectographic analysis requirements. Precise quality control is exercised over every pound of metal in every step of the process, from the zircon sand to the final product.

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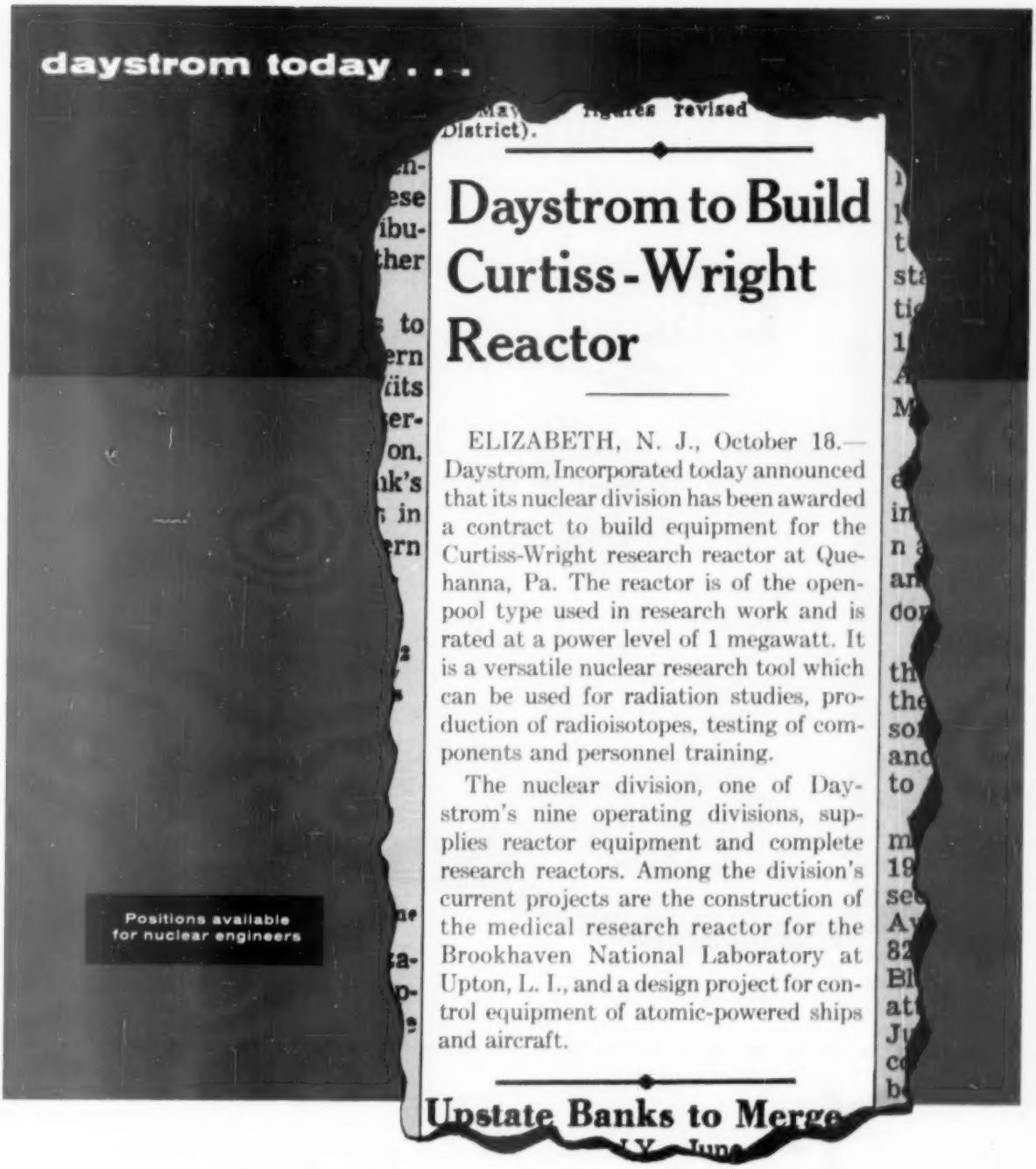

Daystrom to Build Curtiss-Wright Reactor

ELIZABETH, N. J., October 18.—Daystrom, Incorporated today announced that its nuclear division has been awarded a contract to build equipment for the Curtiss-Wright research reactor at Quehanna, Pa. The reactor is of the open-pool type used in research work and is rated at a power level of 1 megawatt. It is a versatile nuclear research tool which can be used for radiation studies, production of radioisotopes, testing of components and personnel training.

The nuclear division, one of Daystrom's nine operating divisions, supplies reactor equipment and complete research reactors. Among the division's current projects are the construction of the medical research reactor for the Brookhaven National Laboratory at Upton, L. I., and a design project for control equipment of atomic-powered ships and aircraft.

Upstate Banks to Merge

DAYSTROM NUCLEAR INSTRUMENTS FOR RESEARCH AND POWER REACTORS

*Composite Safety Amplifier
*Compensated Ionization Chamber Power Supply
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Transistorized Reactor Control Instruments
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*Linear Amplifier
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Custom-built equipment

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ANOTHER EXAMPLE OF
Remote Tongs Adapted for the Small Radioisotope Laboratory
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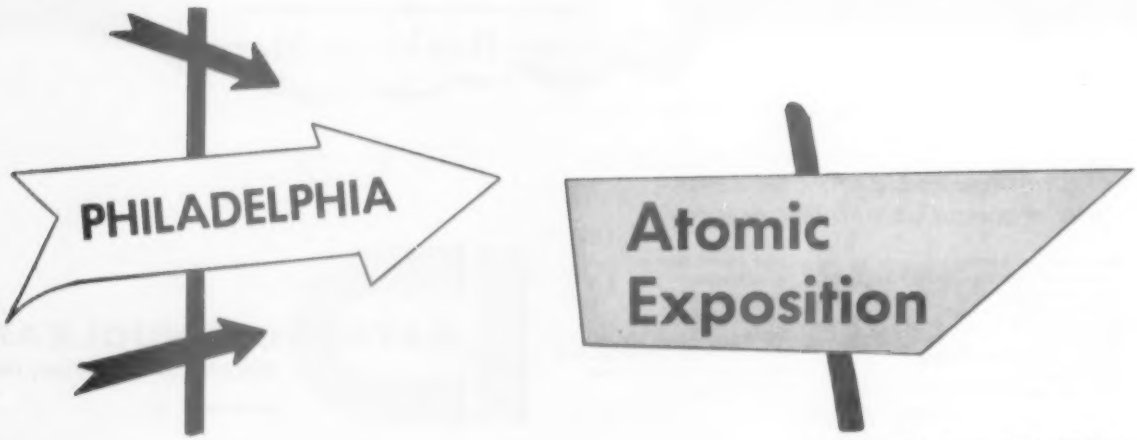
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Atomic Exposition

February Pre-show NUCLEONICS

gets your products top attention at the 1957 Atomic Exposition

Special value to advertisers in the February pre-show issue of NUCLEONICS, reaching the entire nuclear industry before the Atomic Exposition and Nuclear Congress at Philadelphia's Convention Hall, March 11-15, 1957.

- Advertisers exhibiting at the show announce their booth number, merchandise their products and pre-sell buyers.

- Advertisers not exhibiting take advantage of the extra attention given the big NUCLEONICS pre-show issue.

- Advertisers with a show exhibit will receive a plastic display to merchandise their advertisement . . . the same display that was so enthusiastically received at the Atomic Trade Fair.

There will be a special editorial section in this issue with capsule description of the exhibits and a listing of the four-part program of the Nuclear Congress.

Now's the time to start planning your advertisement to get the best results from this valuable issue. The issue will be in the mail in ample time to assure high attendance at your booth.

CLOSING DATES: Copy to set – January 1st; Complete plates – January 8th.

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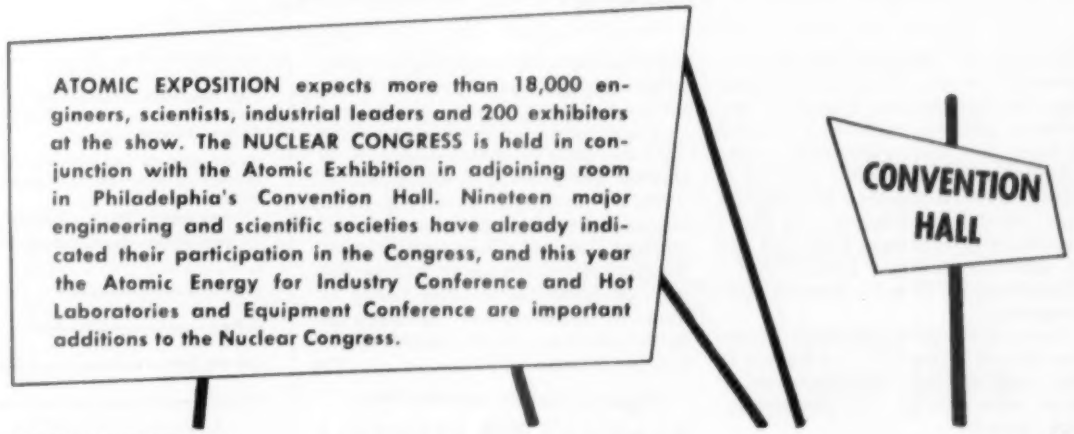
ATOMIC EXPOSITION expects more than 18,000 engineers, scientists, industrial leaders and 200 exhibitors at the show. The NUCLEAR CONGRESS is held in conjunction with the Atomic Exhibition in adjoining room in Philadelphia's Convention Hall. Nineteen major engineering and scientific societies have already indicated their participation in the Congress, and this year the Atomic Energy for Industry Conference and Hot Laboratories and Equipment Conference are important additions to the Nuclear Congress.
CONVENTION HALL

PRIOR TO SHIPMENT, this General Electric a-c electromagnetic pump was given a final mass spectrometer leak test. Manufactured by G.E. for Argonne National Laboratory's EBR-2 reactor test project, this unit can deliver 5000-gpm—highest flow any a-c linear induction-type pump has yet delivered.

Design experience in electromagnetic pumps pays off as . . .

General Electric builds 5000-gpm electromagnetic pump for Argonne Laboratory

The Argonne National Laboratory, operated by the University of Chicago for the Atomic Energy Commission, recently installed a General Electric a-c electromagnetic pump which can deliver 5000 gallons of liquid metal a minute—the highest flow yet delivered by an a-c linear induction-type pump. This unit will be used in Argonne Lab's EBR-2 (Experimental Breeder Reactor) test program.

General Electric's Medium Induction Motor Department is known as the outstanding manufacturer of large, zero-leakage, a-c electromagnetic pumps.

E-M pumps have a column of liquid metal which replaces the rotor of the conventional a-c motor. Thus, without rotary motion, the pumps provide quiet, dependable operation with virtually no maintenance. E-M pumps will operate in any position. Critical problems involving shaft warpage, bearing failures, and faulty bearing seals are eliminated. General Electric electromagnetic pumps can now be built for a wide range of uses in liquid-metal laboratories, power reactors, and industrial chemical processes. 873-5

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Why British Claim Lead in Nuclear Power

At the Geneva Atoms-for-Peace Conference in 1955, British industry impressed several thousand delegates from all over the world with an outstanding and united exhibit from which they boldly announced they were ready to build and sell various versions of the world's first, large, central-station nuclear power plant—Calder Hall. Then, on October 17, 1956, the Calder Hall plant was officially opened. With the facility in operation, the British were then ready to talk about how the plant was designed, engineered and built. This they did in an unusual symposium in London on November 22 and 23.

United Kingdom atomic energy leaders claim they have taken the world lead in nuclear power. This special NUCLEONICS report, prepared in London at the time of the symposium, tells what Calder Hall is, how it fits into the UK nuclear power program, and what it means to the United States and to other countries of the world.

CALDER HALL
REPORT ▸

"Calder . . . is giving us . . . the lead"

Sir Christopher Hinton

"The Calder Hall reactor is giving us the initial lead in the use of nuclear power and we shall be able to retain that advantage for at least a decade by improvements in this type of reactor."

It was with this bold statement that Sir Christopher Hinton, director of the Industrial Group United Kingdom Atomic Energy Authority, set the stage at the opening of the Calder Hall symposium in London, November 22. He was followed by many speakers, from government and industry, who underscored what he said. The total picture was a combination of expressions of satisfaction on a hard job well done, forthright statements about the pre-eminent position accruing to the British as a result of Calder, and an emphatic exposition of why Calder made sense.

The Symposium

These were the overtones felt at the meeting. But the heart of the conference was a very detailed presentation of engineering information on the station itself. Never has there been—even at Geneva—as comprehensive a release of information on any one reactor.

The British wisely waited until the plant was in operation and then they told all—or almost all. The governmental and industrial scientists and engineers who played key roles in Calder told their technical stories, stories that were related from the early beginnings of design thinking right up to the operating product.

What's Ahead

This points to another basic characteristic of the meeting. It was, in a sense, a post mortem on Calder, a plant that is already obsolescent in many ways—a plant whose basic purpose is military, to produce plutonium. This reactor, designed by the AEA, has been made obsolete by the proposals submitted October 1 to the Central Electricity Authority by British firms.

The bulk of the audience at Westminster's Central Hall was actually looking more for more advanced design information on Calder, particularly on plants optimized for power production. But this wasn't forthcoming because, although the winning contractors have already been selected, details on the industrial designs are being withheld until contracts are actually awarded.

Perhaps most disappointed about the lack of more advanced information were representatives from some of the many foreign nations who were present. They were quite specifically seeking to determine how good Calder could be made but only got generalizations.

It must be emphasized, however, that although specifics on the potential of Calder-type reactors were not gone into in any detail, there ran through the meeting the general feeling that much more remains to be done with such plants than has yet been achieved at this early point. In fact, there is very substantial evidence that the British are tying their nuclear future even more to gas-cooled reactors now than they planned to.

One big advantage that the Calder-type unit has is that it uses natural uranium. It is this that has tremendous appeal to many foreign nations who say quite bluntly that they don't want to be tied to U. S. enriched uranium. And it is this that points up one of the biggest lessons to the U. S.—the need to push natural-uranium plants to bolster our competitive position abroad.

Jarvis and Luntz at Symposium

NUCLEONICS Went Abroad . . .

. . . to prepare this special report. Because the British nuclear power program—Calder Hall, in particular—is of great and immediate interest to our world-wide readership NUCLEONICS decided to delay publication of this December issue by one week, to do an on-the-spot reporting job, and to get into print quickly. Editor Jerome D. Luntz flew to London to direct a week-long effort by a five-man team—McGraw-Hill's London Bureau chief, Bill Coughlin; London correspondents, John Tunstall and Morrie Helitzer; photographer, Guido Organschi; and consultant, Ted Jarvis, director of nuclear engineering, Ford Instrument Division, Sperry Rand Corp. (Ford is one of the principal companies concerned with gas-cooled reactors.) Jarvis wrote most of the technical description of Calder Hall appearing in this report. Back in New York, Associate Editor Dan Cooper wrote part of the report and the entire staff pulled the whole thing together.

The story presented here is centered around the symposium on Calder Hall, held on November 22 and 23 by the British Nuclear Conference. To get background and the facts on the British picture, dozens of people were interviewed in London before the conference and during it (at the frigid, unheated Central Hall in Westminster, nicknamed "Calder Hall" by Jarvis).

British Government Speeds Nuclear Program

The British government is taking a new look at its nuclear-power program. The reason for this was made quite clear last month as Britain's nuclear scientists and engineers gathered for the Calder Hall symposium. Even as they met in Westminster's drafty Central Hall, British troops were standing guard over a now-useless Suez Canal through which more than 17-million tons of Middle East oil had moved to the United Kingdom this year.

The Middle East crisis is forcing the Eden government into a critical reappraisal of its planning for atomic power. Previously, the thinking on Britain's nuclear program had been oriented to the need to meet the annual shortage of 20-million tons of coal expected to develop by 1975. Now, it is seen as a means of release from her frightening dependence on Middle East oil.

Britain's Minister of Fuel and Power told Parliament in the same week the symposium met that the government is going to press ahead "at the fastest possible pace" with development of atomic energy. He promised the House of Commons a full statement on the subject before the end of the year.

That statement may well find Britain doubling the atomic energy requirements outlined in its White Paper program of February, 1955. Nevertheless it is not considered likely that this will involve any significant increase in the number of nuclear power stations proposed in the White Paper. It is evident that the goal can be raised by two other methods:

- Official recognition of the technical improvements that already are expected to increase the output of the 12 stations in the first stage of the program two to three times above that estimated in the White Paper.
- Speedup of nuclear power expansion by a "modest crash program" calling for completion of plants each year rather than every 18 months.

Thus, even in the face of its Middle East crisis, Britain can be expected to continue the cautious, conservative approach to its nuclear energy needs that has marked the program to date. The step-by-step attack on the development of nuclear power reactors is not likely to be abandoned.

"We cannot afford to push the industry into a faster rate of expansion than it can safely absorb," one government official states. Under these conditions, Britons are more confident than ever that their decision to go ahead with a power program based on the gas-cooled graphite-moderated reactors of the Calder type has been the correct one.

British Program

The British program is the result of a three-way partnership between the United Kingdom Atomic Energy Authority, the Central Electricity Authority, and the Fuel and Power Ministry.

The British Power Program

A.E.A. Stations [optimized for Pu; power a by-product]

	Output (Mw) Net	*Completion Date*
Calder Hall A	150	'56–57
Calder Hall B	150	'58
Chapel Cross A	150	'58
Chapel Cross B	150	'59

C.E.A. Stations [(the White Paper program) optimized for power; Pu a by-product]

Stage One		
Berkeley, Gloucestershire	250–300	'60
Bradwell, Essex	250–300	'60
Inkley Point, Somerset	300–400	'61
(North Wales?)	300–400	'61
Stage Two		
Four stations	>400	'63
Stage Three		
Four stations	>400	'65

South of Scotland Electricity Board [outside the White Paper program, but also for power first]

Hunterston, Ayrshire	250	300	1960

N.B.—Each of these stations will consist of two reactors, except those in Stage Two and Stage Three, by which time it is expected a single reactor of advanced design will yield the large output shown.

It must be remembered that the Calder Hall station is *not* one of the stations in the Central Electricity Authority's nuclear power program—the White Paper program. Although it is the prototype for the CEA stations, Calder Hall's estimated cost of $56-million was borne entirely by the government through the Atomic Energy Authority. The primary product of Calder Hall is plutonium; electricity is a by-product.

CEA's 10-Year Plan

The 12 nuclear power stations that the CEA is planning in its $980-million program over the next ten years will be designed for maximum power output. The decision on the bids for the first two CEA stations has been reached and will be announced shortly, together with the award for the first station for the South of Scotland Electricity Board. These stations, basically the same physical size and cost as Calder Hall, will have an output in the 200–300-Mw category, thanks to technical improvements not anticipated at the time the White Paper was drawn up. At least eight of the 12 nuclear power stations the CEA will build in the first 10 years of its 20-year program will be based on the Calder-Hall type.

Construction of the first two CEA stations is expected to start in early 1957, aiming at operation in 1960. The construction of the next two stations in the program was to start 18 months after this, in mid-1958. Target date for these two stations may now be advanced to early 1958.

The White Paper calls for an additional four stations to be started in 1960 and another four 18 months after that. These last four are to be more advanced reactors than the Calder Hall type. The decision as to just what type has yet to be made.

Stage Two of Plan

For Stage Two of the program, Harwell and the Industrial Group of the AEA at Risley have been carrying out feasibility studies and research and

development on two liquid-cooled systems requiring enriched fuel: pressurized water and sodium graphite. In April, 1956, the AEA said, "Present information suggests that the choice will probably fall on the sodium graphite system." After that choice, expected to have been made by this time, the next step was to have been the building of an experimental reactor.

An About-Face

But now thinking on the sodium graphite reactor has changed radically in the U. K. One key official put it to NUCLEONICS this way: "Except for a very few people here, everyone is opposed to putting up such a plant."

And so the next six months will be spent taking a hard look at other kinds of systems. Some urgency is given to making a decision by next June because at that time a large design team will become free of other responsibilities in the government's nuclear program.

Meanwhile, a hard push is being put on developing a pressurized water reactor for ship propulsion. However, this type is not being thought of for civilian use because of its requirement for enriched uranium, in very short supply in the U. K. and likely to remain expensive for some time.

In the same connection, plutonium will not be available in quantity from the Windscale and Calder Hall reactors until about 1970. Thus serious consideration for its use probably will not take place until the early 1960's.

As far as Stage Three reactors are concerned, Britain has been looking at four basic systems: fast (experimental plant under construction at Dounreay), aqueous homogeneous, liquid metal fuel, and high-temperature gas. In addition to the sizable group working on Dounreay, there is a team of 70 technicians tackling the homogeneous idea at Harwell.

Gas-Cooled Still Favored

But the one thing that is quite evident is that although the British are examining other reactor types quite carefully, they keep coming back to the gas-cooled reactor with the conviction that they still have a great deal to wring out of it. They are partly moved toward this thought by the feeling that the technology for liquid reactors is quite complex and a bit beyond what they have men for right now.

Despite this skepticism, the British feel their long-range program must be built on liquid reactors. But Sir Christopher Hinton, in his paper before the symposium, most certainly did not rule out a long future for the gas-cooled Calder-Hall type.

"In my view," he said, "the merits of the Calder-Hall type of reactor and the potential improvements which can be made in its design are such that plants of this type will still be built 25 years from now.

"In the second half of that 25-year period, however, it will be replaced in certain land-based applications by reactors of higher rating and in the very long term it will, for most purposes, be superseded by such reactors," he added.

Hinton said reduction in weight per horsepower beyond a certain point will not be possible with the use of gaseous coolants. To advance beyond that point, he stated, higher ratings must be reached which can only be achieved by the use of liquid coolants. Use of these liquid coolants at present is not industrially practical, he added, but warned that this should not stand in the way of development of such reactors.

Looking to Future

The June decision will have a strong influence on the type of reactors selected for the second decade of the British power program, the 1965–75 period. The White Paper does not commit itself to any specific number or type of station after 1965.

The increasing output of the nuclear stations in itself would force a government reappraisal of the program, even without the added urgency of the Middle East crisis. It is estimated that Britain will need at least 60,000 Mw total installed generating capacity by 1975. The White Paper predicted that nuclear power stations might supply as much as 15,000 Mw of this. With the rating increases now anticipated, it is apparent that the nuclear stations might be able to supply as much as 30,000 Mw, half of that needed.

This development alone would force a new evaluation of the relationship between nuclear stations, coal-fired stations and oil-fired stations. Some Ministry of Fuel and Power officials now believe all new stations built after 1968 will be nuclear stations.

The White Paper anticipates the nuclear output of electricity will ease the strain on Britain's hard-pressed coal industry. But the increases now being discussed are of a magnitude actually to threaten the coal industry, particularly since there is a preference for oil when available. This could strengthen the government's research program for converting coal into gas and oil, a move already indicated by the Suez crisis.

Other Economic Effects

There are other ways in which the increasing impact of the nuclear program will affect the British economy. Past planning has envisaged the nuclear stations taking the base-load, with coal- and oil-fired stations being pressed into service for peak-loads. Installation of a larger nuclear capacity may give added impetus to increasing its use in off-peak hours, since it will further decrease its cost, providing extremely cheap base-load electricity. (It is, of course, undesirable to shut down a nuclear station when the load falls, as can more easily be done with coal and oil stations.)

One official at the Ministry of Fuel and Power believes this could lead to low night tariffs, offering a million BTU's for as little as 70¢. Use of stored heat and stored steam could then become an important factor for industry, with low night tariffs encouraging a spread of peak loads. There would also be a tremendous advantage in increased use of pumped-storage stations, combining cheap nuclear power with cheap hydroelectric power.

The quickening pace of nuclear development therefore carries an import for all of Britain's economy that no one yet has had time to assess fully.

Oil Threatened

Realization of the threat to oil—Britain depends on the Middle East for 75% of its oil—has made nuclear development even more of a necessity. Sir Claude Gibb of C. A. Parsons & Co. Ltd. brought this out strongly at the symposium when he declared: "We must make ourselves independent of minor despots and their whims."

He asserted that the techniques are at hand and that British industry is ready to tackle the job. But it will take more than just willingness on the part of the firms engaged in nuclear work. Gibb put it quite flatly: "Only the government of the day can decide the rate at which we exploit our lead in nuclear power."

Steel already is in short supply in Britain and is barely sufficient to support the atomic program as it is now laid down. If that program is to be stepped up, steel becomes a major problem. To make matters worse, any cutoff of supplies from the Middle East will have its effect on steel output. The steel industry is the biggest user of fuel oil in Britain. Some two-fifths of the industry's output of crude steel is produced in oil-fired furnaces. Even with no more than the present drop in oil supplies to Britain, the nation faces a loss of ¾-million tons of steel.

Need For Planning

Some far-sighted government planning across all of industry will be required in order to step up the British atomic energy program, even if additional stations are not called for.

British industry came belatedly into the nation's atomic planning. Initially, atomic establishments were built to designs prepared in the Ministry of Supply and Ministry of Works. When completed, the Ministry of Supply provided the operating staff.

The Atomic Energy Authority admits frankly: "The creation of the country's first atomic energy facilities provided little opportunity to industry to acquire practical experience of the techniques of this new field."

But when the Central Electricity Authority's nuclear power program was announced early last year, the government made it plain that private industry, not the Atomic Energy Authority, would design and build the stations. The AEA announced that dissemination of information to industry was regarded as one of its prime responsibilities. One method through which this is done is the reactor school set up at Harwell to train industry representatives in construction and operation of nuclear reactors.

The Authority also has announced that it will provide natural uranium fuel elements to match whatever volume of export business British industry may achieve. With this encouragement, some U. K. firms are quoting prices of about $56,000/metric ton for natural uranium fuel fabricated.

Looking Abroad

Differing with British industry, the government does not anticipate any large export of nuclear reactors in the next few years. Its attitude is summed up in the statement: "It is reasonable to expect that orders from overseas will follow, rather than precede, the achievement of nuclear power on a competitive basis in this country."

And Plowden adds: "We believe it will be at least 10 years before competitive nuclear power stations of (30 Mw) size have been fully developed and tested and are available for large-scale use. There are, however, some countries, such as India, Turkey and Egypt, where a few large thermal power stations of about 100 Mw are planned.

The government feels it can best serve the export interests of industry by laying down a sound domestic program. The interest of foreign observers at the Calder Hall symposium indicates this attitude is paying off.

Any expansion of Britain's nuclear program—and the Calder Hall symposium left little doubt of the enthusiasm that has been generated—inevitably will require some additional thought about the nation's international relationships in the nuclear field, particularly with the rest of Western Europe.

Sir Christopher Hinton, Sir Edwin Plowden, R. F. B. Bennett, parliamentary secretary at Fuel and Power Ministry, Geoffrey Lloyd, Minister of Fuel and Power, and Lord Citrine, CEA chairman (l to r), inspect a model of Calder Hall

Euratom vs O.E.E.C.

Britain has not yet decided whether to go into the close-knit Euratom proposal or to adhere to the looser O.E.E.C. organization. Neither plan, of course, is in its final form, but the United Kingdom has shown a reluctance toward the Euratom project, particularly in regard to its proposed control of raw materials.

"It really would be asking too much to expect us to give up our own supply contracts with countries like the Belgian Congo and Canada and to hand them over to other countries which have not such a supply system," says one politician.

O.E.E.C., which would permit nations to come into the organization to the extent that they wish without such binding agreements as those of Euratom, offers more appeal to the British at the moment. What effect an expanded atomic program will have on this thinking is uncertain, but it should swing Britain even more to O.E.E.C.

How swiftly recent events have changed attitudes toward the nuclear power program can be seen in the following statement made in the House of Commons on November 12: "It is only when coal, plus atomic energy, has been able to supplant oil that we shall be able to get out of the unhappy and dangerous position of being black-mailed by the oil-producing countries."

It was only a few short weeks ago that oil plus atomic energy was seen as an escape from a sorry coal situation. The one constant has been nuclear power. In that fact lies Britain's hope.

British Industry's Goal:

A Better Calder for the World Market

As in the U. S., the British nuclear power industry began as a Government monopoly—a complete monopoly on basic knowledge, design, construction, technical know-how. But unlike the Americans, when the British decided the time had come for industry to participate as an equal partner they proceeded in a much more paternalistic manner. The British government, late in 1954, set about the organization of four consortiums or syndicates of large industrial concerns. It invited the four leading electrical equipment firms in Britain to study the Calder Hall type of reactor, to take into partnership a leading boilermaker and a civil engineering contractor, and to send teams to study at Harwell.

The four groups thus formed are

- Nuclear Power Plant Co.;
- General Electric Co.–Simon Carves;
- English Electric Co.–Babcock & Wilcox Ltd.–Taylor Woodrow;
- Associated Electrical Industries–John Thompson.

As their first task, they were asked to bid, in competition, on the first two power stations for the Central Electricity Authority's ten-year White Paper program, and for a station for the South of Scotland Electricity Board. All are to be improved Calder-type plants. The bids have been submitted, and awards are to be made in January.

A Roundup

Four points emerge from a survey of the activities of the four consortiums.

1. The development effort has been 90–95% solidly behind graphite-moderated CO_2-cooled systems.

2. Groups are offering fixed-price bids for complete nuclear power stations, comparable operating costs per unit generated with the best thermal stations, and guaranteed performance and construction time.

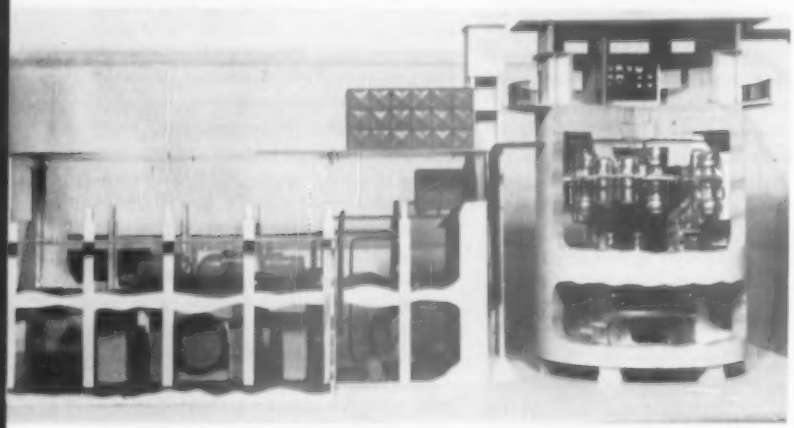
3. Development potential revealed during the last two years by the consortiums greatly exceeds expectations and makes a major development switch from gas-cooled reactors unlikely in the next ten years.

4. The fact that the gas-cooled plant gets by on natural uranium is proving a very valuable selling point in the export field.

Interest in all other systems does not absorb more than 10%—if that much—of the development and research capacity of any one of the groups; and it is slanted to the accumulation of corrosion and heat-transfer characteristics with liquid-metal coolants, rather than to specific system development. According to the group leaders, supremacy of graphite-moderated gas-cooled systems using CO_2 is assured in the power-generation field for at least the next 10 years; its usefulness is assured for the next 25. There is naturally a realization that systems using enriched fuels are inevitable, especially in the 30–50 Mw power bracket, but work will proceed upon them only as long-term policy. It appears that no group can hope to match Harwell's metallurgical research and irradiation facilities, and consequently any switch to alternative systems will need to depend on Harwell's guidance. Whether Harwell should exploit this situation financially is now being reviewed.

In achieving major advances in the Calder design, emphasis was placed by the industrial groups on the fact that no major design changes had been or were likely to be involved—perhaps only one group departed from the basic concept of a right cylinder for the reactor vessel. But gas pressures probably twice those at Calder have been used: this because better low-carbon steel alloys have been evolved and because advanced welding techniques have become available, permitting on-site welding of 3-in. plate. These factors alone were sufficient to make the most significant contribution to the increased specific ratings of the first bids.

The basic unit reactor size in all the first CEA proposals is several times greater than Calder Hall and appears to lie between 100 and 150 Mw. No serious development effort is apparent on units much below 100 Mw but at least one group is developing upward to 200 Mw units.



Model of boiling water reactor station proposed to CEA by Mitchell-AMF Atomics group

It is clear that considerable capital cost reductions on Calder Hall have been achieved, with at least one group quoting a figure as low as $280/kw installed capacity. The AEI–John Thompson group has even set its target for the next round of CEA bids at $250/kw installed. This figure nearly matches the price of $210 quoted to CEA by a new industry grouping, AMF–Mitchell Engineering, for a pressurized water reactor.

Construction times for, say, a 300-Mw station seem to be rated at about 4 years. Some groups speak of working up to one 300 Mw unit a year, with three to four in hand at any one time.

Graphite could be an immediate bottleneck, with 3-in.-thick rolled plate running close second, but provision is being made to boost production capacity of both commodities.

Workload Distribution

Each of the four main groups has now spent $1.5–2 million in establishing research and development facilities and preparing its first bids.

Distribution of the research and development load is different within each group. This is reflected in the design teams recruited—these range from 150 to 250 personnel—and in the varying extents to which member companies have assigned workers to the nuclear program. Research teams include pure and applied mathematicians, physicists and chemists, but are most heavily loaded with metallurgists and mechanical engineers. About half the teams are professional.

In two cases—the G.E.C.–Simon Carves and the English Electric–B & W –Taylor Woodrow groups—new project and design research laboratories were established alongside the mechanical engineering plants of the electrical company concerned. The two other major groups—Nuclear Power Plant Co. and AEI–John Thompson—have established independent project design offices, and research and development work is undertaken on plants of the electrical and steam firms in the groups.

Research Programs

The research programs of each group are basically similar. But the nature of the crash research program in each case has led to a number of highly ingenious, improvized metallurgical and heat transfer rates being evolved.

Much of the improved performance obtained by the groups with the gas-cooled graphite-moderated reactor arises from the use of higher gas temperatures and pressures, development of improved canning materials, and improved and stronger finning on fuel cans to withstand the very high heat and pressure loading involved. Major problems involve corrosion and oxidation of the can (believed in most cases to be magnox alloy—a magnesium-beryllium alloy), and of the steel shell in a wet CO_2 atmosphere; and the creep and fatigue properties of the fins. An increasing percentage of the metallurgical effort is now going into other canning materials such as zirconium and beryllium alloys.

All groups have examined many orientations of the fin to the gas flow, particularly transverse as used in Calder Hall. But in the final analysis, fabrication economics plays a big part. Different can-fabrication techniques have been investigated throughout the industrial groups, including that of impact extrusion of the can together with longitudinal fins, the helix being obtained by twisting. Among the novel equipment evolved is: thermo-balancing apparatus that gives a continuous weight reading while oxidation tests proceed; batteries of heat treatment furnaces using heated and pressurized CO_2 atmospheres; batteries of rigs on which the all-important stress/corrosion tests can be conducted simultaneously; apparatus for examining radiographically the "ratcheting" effect of the fuel rod in the can under thermal cyclic loading.

Heat transfer rigs show the most ingenuity throughout the groups. These operate with CO_2 under controlled conditions of pressure and temperature with provision for measuring gas temperatures, pressures, flow rates, and can temperatures to give a heat balance. A feature of group facilities in this department are the quick sampling rigs that operate with atmospheric air and make it possible to eliminate at an early point unsuitable finning arrangements. More importance has come to be attached to oxides and to surface roughness along the heat transfer interfaces.

No less importance attaches to the design and welding of aerodynamic fins needed to extend the heat transfer surfaces on the water side for the least pressure drop. One rig passes dry superheated steam through the tube which is externally air-cooled. The amount of steam condensed is then used to relate the effectiveness of different finning arrangements in the shortest possible time.

All groups have developed charge and discharge fuel loading equipment that can operate under system gas at pressure. It was a requirement that fuel elements be changed without shutting the reactor down. Other mechanical design developments by various groups include novel gas seals and gas bearings that are preferred to molybdenum disulphide solid lubricants by at least one group where normal lubricants are not permissible.

Little work has been done on either helium or hydrogen coolants, which offer both nuclear and thermodynamic advantages. Groups have been frightened away from hydrogen because of its ability to diffuse through the cans into the uranium with which it has a

G.E.C.'s analog computer, only one of kind in Britain, designed to simulate performance of any part of nuclear power station

dangerous affinity, from helium because it is not domestically available.

Marketing

All groups report firm inquiries from Germany, Italy, Japan, South American and Commonwealth countries, but in general no company has yet applied positive sales pressure, deeming it premature until the CEA stations are under way.

One thing has become quite definite: most European countries are favorably disposed to the gas-cooled graphite-moderated station because it requires only natural uranium which is plentiful and absolves them from complete dependence on a particular country for the supply of enriched fuels.

It is also clear that if nuclear stations are to break into the field dominated by fossil fuel use, stations will have to be something less than 30 Mw. This means enriched fuel would be required, and investigations of the high temperature gas-cooled reactor using enriched

Sir Claude Gibb at symposium

fuel are becoming high-priority matters in the industrial research program.

The Four Industrial Groups

The Nuclear Power Plant Co. embraces eight member firms, each contributing to the cost of a central project design office in Knutsford, Cheshire. It is now staffed by 200 technologists, about half of them professional. Each member company has diverted further teams of up to 60 men on its own premises to take the nuclear research and development load in its own field.

One of the group's principal beliefs is that improved mechanical and control details of the Calder Hall type of reactor could lead to big capital savings. In particular the company intends to develop unit reactors both larger (200 Mw) and smaller (100 Mw) than Calder Hall, the latter probably being the most important in the export field.

Only a small percentage of the professional personnel has so far been investigating other reactor systems, then mostly the basic heat transfer and corrosion problems associated with liquid coolants. At this stage the group had not exercised any pressure on the selling side but is prepared to develop firm inquiries.

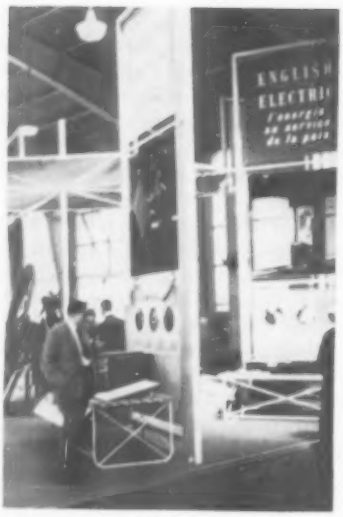
Member companies of this group have made large contributions to Calder Hall and Chapel Cross. C. A. Parsons & Co. Ltd., who supplied the turbo-generator and gas circulating blowers for Calder A, will handle this equipment, ductwork and associated instrumentation for the group. Parsons is the largest turbo-generator concern in Europe and pioneers of the steam turbine.

Whessoe Ltd., with a history dating back to 1790, were assigned the Calder Hall reactor vessel and will be responsible for this item. Whessoe is considered to have unsurpassed experience in site-welding of heavy plant construction. It has tackled most of the large supersonic pressurized wind tunnels in Britain, pioneered the construction of high pressure gas-holders and caterackers there. It has already tooled up for batch production of eight Calder Hall type reactor vessels.

Sir Robert McAlpine & Co., the building and civil engineers to the group, were among the first advocates of reinforced concrete in Britain and claim to be the most mechanized British company in this field. Contracts have included 20 large thermal stations, oil refineries and steel works. Alex Findley & Co. Ltd. will supply structural steel and general fabrication.

Reactor equipment and heat exchangers will be supplied by Head, Wrightson & Co. Ltd., another leading British company about to celebrate its centenary. The firm makes complete process plants in the coal, gold, iron and steel, oil and chemical industries and has specialized in heat exchange equipment. It has seven subsidiaries in Britain, including iron and steel foundries, forges and fabrication shops. It produces a range of alloy steels and has extensive metallurgical research facilities. At present, Head, Wrightson has the most experience with heavy water research reactors in Britain.

The group have secured Strachan & Henshaw Ltd. to supply the fuel handling equipment. This company has



A corner of British industry exhibit at Geneva conference in 1955

had extensive mechanical handling contracts for the U. K. AEA, including the fuel handling equipment for Calder Hall and Chapel Cross.

A. Reyrolle & Co. Ltd., switchgear and control gear makers to the group, has also been a large supplier to the Harwell, Windscale, Springfields, and Capenhurst establishments of AEA, and made the switchgear at Calder Hall and Chapel Cross. The company claims to be the largest maker specializing in switchgear equipment in the world. Reyrolle recently opened a new plant to fabricate and machine reactor graphite.

Completing this group is Clarke Thompson & Co. Ltd., who will supply steam raising, crane and lifting gear.

To coordinate the work of the eight member companies, the firm engaged the Parolle Electrical Plant Co. Ltd., jointly owned by Parsons and Reyrolle. This company has had a design team based at Harwell or Risley since 1947.

English Electric-B & W-Taylor Woodrow group has located its nuclear project design division at the Whetstone works of the English Electric Co., where much of the engineering and metallurgical development of the group is centralized. It includes about 100 professional people in a staff of 250.

The group pools much experience gained by its member companies at Calder Hall and Chapel Cross. Taylor Woodrow Ltd., brought in to carry out the crash building and civil engineering program at Calder Hall, is one of

Britain's largest civil engineering firms.

The English Electric Company, as one of Britain's main electrical contractors, will provide the turbo-generating and associated electrical equipment and all the instrumentation.

The pressure vessel and heat exchangers will be supplied by Babcock & Wilcox Ltd., foremost steam generating plant engineers in Britain and supplier of the Calder Hall heat exchanger plant.

Plans of the Babcock & Wilcox organization are the most ambitious of any single company in the four consortiums. Though intending to remain in the group to work on Calder Hall type reactors, its ultimate goal is the design and fabrication of complete nuclear power stations. These will include pressurized water reactors, probably with fossil fuel superheating. This, the company contends, is a natural development for a company making boilers and steam plant. It plans eventually to reach steam conditions of 900° F and 250 psi with gas-cooled reactors, using sintered beryllium–uranium fuel elements.

The company's production lines already wear a nuclear look. An impressive line has been established for the production of the Calder Hall A and B and Chapel Cross heat exchangers. A new tube and manifold plant costing $2.6-million enables mass production techniques to be applied in the fabrication and assembly of the heat exchanger, shell and tubing. Equipment includes batteries of automatic welding plant for studding the aerofoil fins onto the tubes. (Some 340-million are used on the 32 towers for Calder and Chapel Cross). Other new plant includes large stress relieving ovens; new presses, one of 2,000 tons for dishing plate up to 8 in. thick; increased facilities for acoustic and radiographic testing. The machine shop has also been reorganized and equipped to match the flow lines established for welding and fabricating reactor assemblies.

At the company's Renfrew, Scotland, research establishment, there are 270 technicians—well over half of them professional. Special metallurgical equipment recently installed includes latest types of spectrographic apparatus for the all-important measurement of trace elements; simulated scaling apparatus on which scaling losses can be predicted during 100,000 hours; 84 new hot-stress rupture machines; rigs on which ratcheting of fuel in the can under thermal cycling loads can be radiographed.

G.E.C.–Simon Carves has established its nuclear department at Fraser & Charmers engineering works, Erith, where most of the heavy mechanical plant for the General Electric Co. is made. Strength is up to 250 technologists—100 professional, of whom 75% are G.E.C., 25% from the Simon-Carves group of companies.

As its pressure vessel fabricators, this group has taken in the Motherwell Bridge & Engineering Company, which is building the sphere for the Dounreay reactor. None of the member companies was associated with the Calder or Chapel Cross stations. John Mowlem & Co. will handle the building and civil engineering program.

G.E.C. is the second largest electrical manufacturing group in Britain, has a capital of $180-million and a total payroll of 71,000.

Again, effort is largely channelled to gas-cooled graphite-moderated reactors; about 10% of professional staff is working on general problems of corrosion with liquid metal coolants, principally Na, NaK, and some undisclosed slurries. Homogeneous reactors form no part of the planning; the group has no interest in water reactors because of "bad steam conditions."

Research equipment includes several ingenious rigs, and the company was the first to install an analog computer for analysing transient reactor operating characteristics.

Unit size of the company's reactor is 150 Mw, and it has already submitted a bid of this size, based on the CEA proposal, to a Continental and a Commonwealth country.

AEI-John Thompson Nuclear Energy Co. Ltd. is one of the groups making a big bid for leadership among the consortiums. Associated Electrical Industries Ltd., which includes Metropolitan-Vickers Ltd. and the British Thomson-Houston Co. is the largest electrical group in Britain; John Thompson group of companies includes several large chemical and steam plant subsidiaries and a contributor to the Dounreay reactor.

The nuclear division is located at Knutsford, Cheshire, and presently employs 100 technicians, plans to have 300 by mid-1957. The group is now building up facilities to investigate several reactor systems but has so far worked exclusively on Calder type reactors. One of its activities has been the development of electromagnetic liquid metal pumps; it also offers a research reactor commercially.

Other Firms

In addition, Mitchell Engineering Ltd. and AMF Atomics of New York have decided to collaborate—the only such case of Anglo-American partnership. Mitchell designs, erects and installs complete power stations and claims to be the largest private company in the world. Annual turnover reaches $140-million. All the nuclear aspects of the group are handled by AMF Atomics of New York. The reactor it will offer is a closed cycle boiling water unit operating at 900 psi and 900° F. Installed cost is $210/kw. Power stations will be compounded from 20 Mw or 30 Mw units.

J. V. Dunworth of Harwell with H. S. Arms, head of English Electric-B & W-Taylor Woodrow group

Another newcomer to the industrial nuclear power field is the Hawker Siddeley Nuclear Power Co. This group now has a laboratory-equipped team of 60 people working on small homogeneous reactors of 3 Mw and up. Both steam and gas turbine prime movers are envisaged, depending on the availability of water. The company has substantial government backing. At the moment, its effort is concentrated mainly on the corrosion problems of the system using standard equipment and techniques. Applications include marine propulsion, but it is generally intended for industrial power generation. The company is aiming at replacing the diesel engine with its dependence on oil.

Rolls Royce Ltd. also has its finger in the nuclear power field with at least one marine application and an interest in nuclear propulsion for aircraft; but the whole of the company's program is heavily shrouded in secrecy.

Calder Hall | Over-All Description

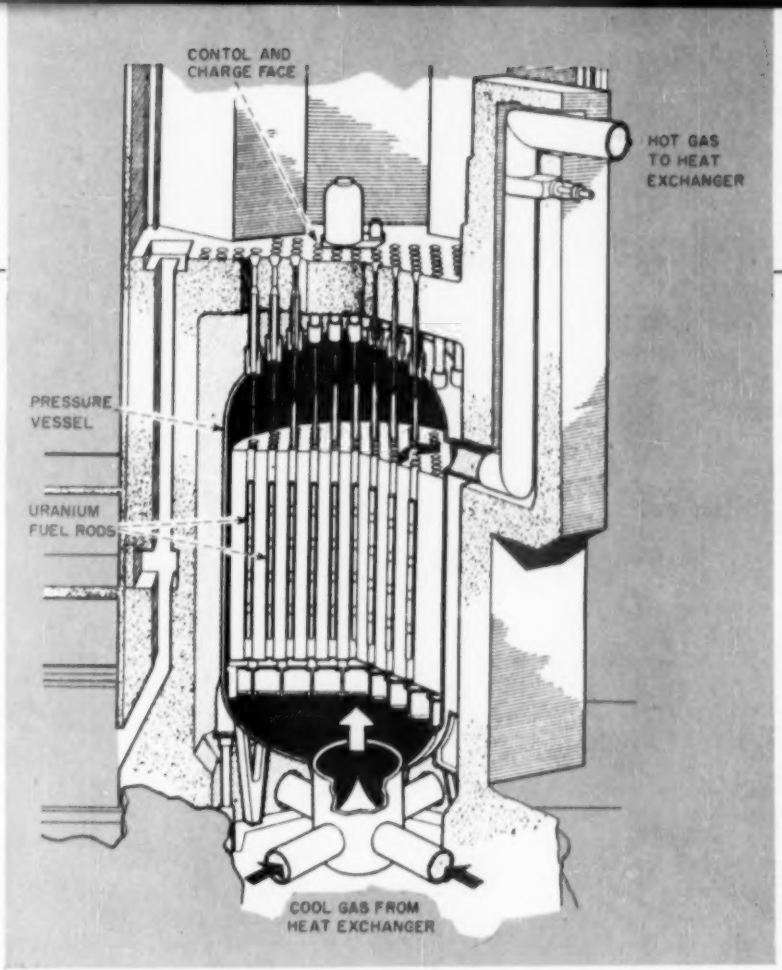
The design for the reactors in the Calder Hall Atomic Power Station is based on a proposal made at the U. K. Atomic Energy Research Establishment at Harwell to build a small power reactor called PIPPA to supply the Establishment's needs for electricity. That reactor was never built. In February, 1953, authorization was given for a reactor to produce military plutonium, adjacent to the two operating plutonium-production reactors at Windscale between the Irish Sea coast and the River Calder in Cumberland. Unlike the two earlier reactors, however, this one was to produce electric power as a by-product. A few months later, approval was given for a second reactor as part of a two-reactor plant. The original PIPPA design, which had emphasized power production, was modified following the shift in emphasis to maximizing Pu output. Construction work began in summer 1953.

Early in 1955 the Atomic Energy Authority decided to erect a second two-reactor plant, now designated "Calder B," next to the plant then rising, and four additional reactors of the same design at Chapel Cross near Annan, Scotland. A large graphite-moderated thermal-neutron reactor, Calder uses natural uranium clad in magnesium alloy as fuel. Power output, originally to be 50 Mw, has been boosted to 92 Mw by redesign.

Most Complete Set of Calder Hall Characteristics Yet

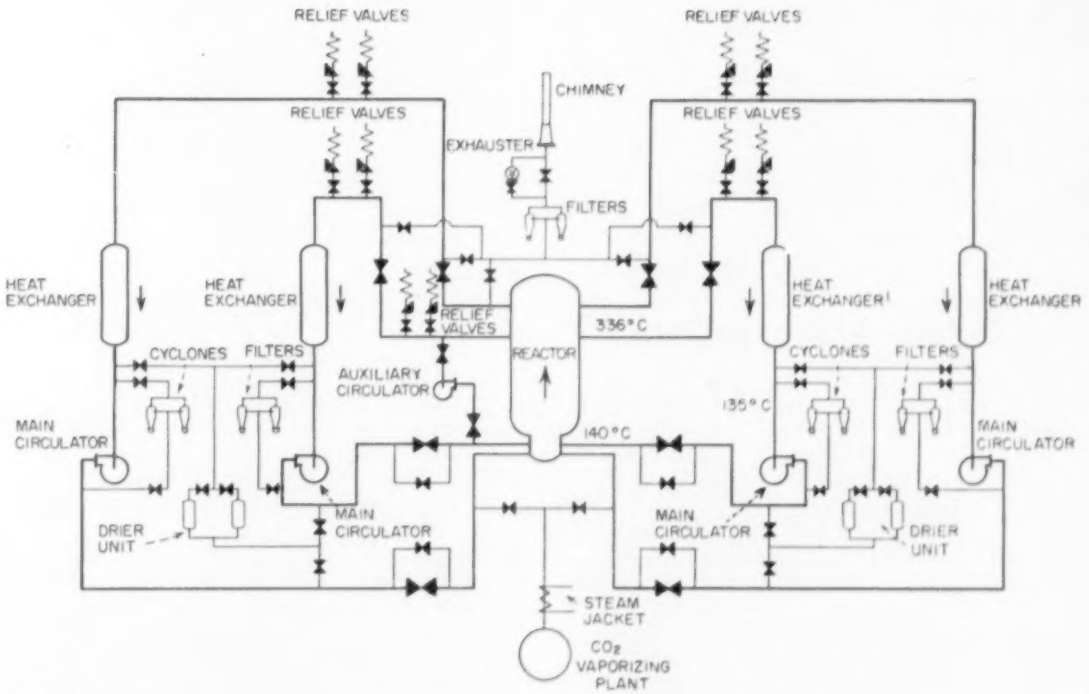
Over-all	
Reactor thermal output, Mw	182
Reactor coolant outlet temperature, °F	637
Reactor coolant inlet temperature, °F	284
Reactor coolant mass flow, lb/sec	1,964
Net electrical output, Mw	39
Net over-all thermal efficiency, %	21.5
Reactor Core	
Fuel	Natural U
Total weight of fuel, tons	130
Number of fuel-element channels	1,696
Diameters of fuel-element channels	256 are 4.16 in. 576 are 3.95 in. 864 are 3.61 in.
Pitch of channels, in.	8
Number of control-rod channels	112
Diameter of control-rod channels, in.	3.25
Nominal core height, ft	21
Nominal core diameter, ft	31
Height of graphite, ft	27
Diameter of graphite (across corners), ft	36
Machined weight of graphite, tons	1,146
Core graphite density,* gm/cm³	1.73
Core graphite absorption cross section* (measured in air in GLEEP), millibarns	4.0
Reflector graphite density,* gm/cm³	1.60
Reflector graphite absorption cross section* (measured in air in GLEEP), millibarns	4.8
U rod diameter, in.	1.15
Length of U in channel, ft	20
Density of U,* gm/cm³	18.7
Absorption cross section of cans and supports, cm²/ft U	0.51
Reactor pressure vessel	
Inside diameter, ft	37
Thickness of shell, in	2.0
Design stress at 752° F, psi	12,000
Working pressure, psig	100
Main CO_2 ductwork	
Numbers of ducts in parallel	4
Diameter of ducts, ft	4.5
Mean coolant velocity (hot ducts), ft/sec	74
Mean coolant velocity (cool ducts), ft/sec	49
Main CO_2 circulators	
Number of circulators	4
CO_2 flow rate per circulator, lb/sec	500
Pressure rise in circulator, psi	5.53
Isentropic efficiency at design point, %	78
Shaft power to circulator motor, h.p.	1,495
Electrical power required (4 circulators), Mw	5.44
Main heat exchangers	
Number of heat exchangers	4
H.P. steam flow rate, lb/hr	396,000
H.P. steam exit temperature, °F	595
H.P. steam exit pressure, psia	210
L.P. steam flow rate, lb/hr	118,600
L.P. steam exit temperature	350° F
L.P. steam exit pressure, psia	63
Feedwater temperature, °F	100
Turbo-alternators	
Number of sets per reactor	2
H.P. steam temperature, °F (at T.S.V.)	590
H.P. steam pressure, psia (at T.S.V.)	200
L.P. steam temperature, °F	340
L.P. steam pressure, psia	53
Flow-rate to condenser per set, lb/hr	257,300
Vacuum at turbine exhaust, in. Hg	28.25
Gross electrical output of each turbo-alternator, Mw	21.0

* Used for calculations.



CUTAWAY view of Calder Hall reactor reveals general configuration

FLOW DIAGRAM of main CO_2 system at Calder Hall shows relationship between main and secondary components of reactor unit. Coolant enters base of reactor at 100 psi gauge and 284° F, and leaves top at 637° F in four parallel and identical circuits. Each includes a heat exchanger in which heat is removed from CO_2 to raise steam for turbines, and a main coolant pump in low-temperature leg. Isolation is provided by valves of wedge-gate type in both inlet and outlet ducts



Calder Hall | *Initial Operation*

First Operating Experience

The Calder Hall reactor went critical on May 22, 1956. On August 8 it generated 100 Mw (thermal) and on September 3 it generated 28 Mw (electrical). On October 17 the reactor was dedicated by Queen Elizabeth II, and power was first sent into the national grid. On November 5 the plant had its first scheduled shutdown. This is the first of several routine check-ups which will take place during the six months commissioning period of each of the two Calder Hall reactors. The difficulties which have apparently occurred are:

Fuel Elements. This first inspection stressed checkup of the lowest of the six uranium fuel elements in each channel. Each one of these must carry the considerable load of the five fuel elements resting above them in the channels.

This recent examination of lower fuel elements is thought to have led to urgent reappraisal of the snag problem. The number one problem now appears to be the effect of irradiation on fuel elements. This can lead to bowing, particularly of lower and most heavily loaded elements, but the exact condition of the rods has not been disclosed as of this writing.

Instrumentation. The usual debugging of the instrumentation and the elimination of false danger signals is now proceeding.

Contamination. Some contamination of the charging face of the reactor has occurred, but as far as is known the activity levels are not serious.

Leakage. The Calder Hall reactor is apparently leaking somewhat more than one ton of CO_2 per day. The coolant is not particularly radioactive so that no hazard exists. The total leakage seems to be a result of a sum of many small leaks and not due to a single failure. Detection and elimination of leaks is now proceeding.

Loss of coolant is not considered a hazard or important, therefore they are waiting for Calder B reactor to come on line before shutting down and pulling up properly on all seals and joints.

Flux Distortion. From the data available to date it is quite likely that the actual reactor flux and power generation distribution depart appreciably from the predicted values. The predicted and measured conditions are:

	Predicted	*Measured*
CO_2 gas flow rate, lb/sec	491	581
Gas temperatures, °C		
Heat exchanger inlet	336	312
Heat exchanger outlet	135	136
Heat to water and steam, Mw	46.15	47.8

The important difference between values is in the heat-exchanger-input (reactor-output) temperature. The maximum outlet temperature achievable is 24° C lower than the design temperature. The most likely cause of this difference is the presence of hot spots due to poor flux distribution in the reactor. To compensate for the lower reactor-output temperatures, the gas flow rate has been increased substantially to keep the same output thermal power. It was stated that the reactor had more excess reactivity than expected and it is possible that excessive control rod insertion or perhaps some fuel element removal caused poor flux distribution.

How Calder is Started Up

What follows are the steps normally required to bring the Calder plant up to power, not the more complicated procedures used when it first was started up.

Phase 1. All heat exchangers are brought on line, heating up "dead" circuits with steam from the external supply before opening the main CO_2 gas valves.

Phase 2. Commence to withdraw control rods. Close up the gas system and charge with gas to a pressure appropriate to the mean temperature (about 60 psig). The time to fill is about 2 hr, and in the same time the reactor power will have risen to a few kilowatts.

Further withdrawal of the rods raises power to 1 Mw in about 10 min. At this point the ionization chamber connected to the low-level logarithmic d-c amplifier circuit must be withdrawn from the thermal column.

Phase 3. Establish full permissible gas flow, and withdraw rods at a rate which raises fuel-element surface temperature at 2° C/min. The gas temperature rises in sympathy; at 250° C sufficient H.P. steam is being generated to enable a turbine to be started. By the time the outlet gas temperature from the reactor reaches 300° C, the set could be up to speed and sufficient steam available for starting the second turbine.

Phase 4. Raise power and mass flow at substantially constant temperature until the reactor is brought to power.

Calder Hall | Reactor Physics

UNDERLYING any reactor design are the nuclear calculations that determine the parameters of the reactor core. The group constants of the Calder Hall reactors are listed in Table 1 for natural-U fueling and reactor filled with CO_2.

In addition to these, some relevant constants have been computed from the data in the table and other information available:

Conversion ratio 0.85

Temperature coefficients for clean reactor are $\sim -2.5 \times 10^{-5}/^\circ$ C for U metal and $\sim -7 \times 10^{-5}/^\circ$ C for graphite.

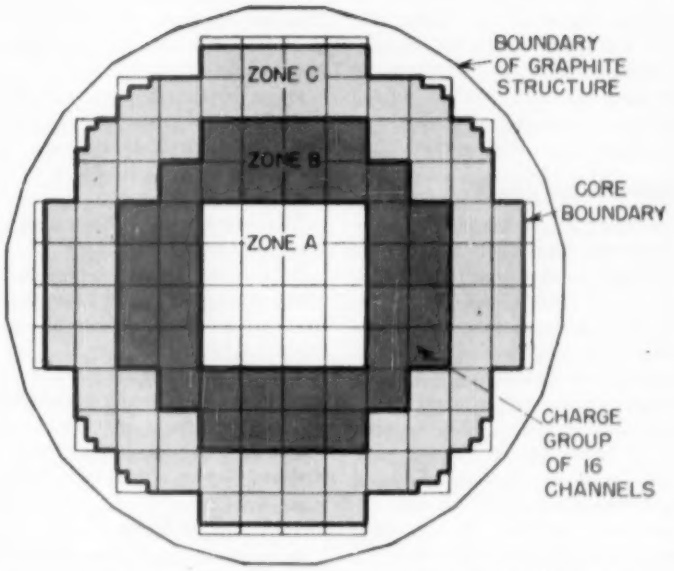
Equilibrium xenon contribution to reactivity is given as function of specific power level in Table 2.

It is planned to operate the Calder Hall reactor as far as possible, with minimum control-rod insertion. By changing fuel elements at staggered intervals and making use of the initial reactivity increase, caused by the conversion of U to Pu the reactivity fluctuations will be kept low.

The control rods may be used to shape the neutron flux but no core loading for flux flattening will be done. The fuel-element-surface-temperature distribution will be flattened in the radial direction by the diversion of the reactor into radial zones of varying graphite channel size as shown in the figure and by using flow constriction within each zone.

TABLE 2—Equilibrium Xenon

Power (Mw/ton)	*Xe reactivity*
2.5	1.6%
2.75	2%
3.0	2.4%



Arrangement of core zones, charge groups, and side reflector. Channel diameter was chosen as 4.16 in. in zone A, 3.95 in. in zone B, and 3.61 in. in zone C

TABLE 1—Lattice Constants for Calder Hall Reactor*

	Core			*Reflectors*		
Constant	*Zone A*	*Zone B*	*Zone C*	*Top reflector*	*Bottom reflector*	*Side reflector*
Inner radius, ft	0	6.02	10.85	3.25†	2.67†	15.49
Outer radius, ft	6.02	10.85	15.49	—	—	18.00
Channel diameter, in.	4.16	3.95	3.61	—	—	—
No. of channels	256	576	864	—	—	—
Thermal utilization factor f	0.93186	0.93010	0.92672	—	—	—
Resonance escape factor p	0.87533	0.87861	0.88398	—	—	—
Fast fission factor ϵ	1.02972	1.02972	1.02972	—	—	—
Thermal fission factor η	1.26595	1.26595	1.26595	—	—	—
Multiplication constant k_∞	1.06330	1.06527	1.06789	—	—	—
Radial diffusion area, cm²	406.6	391.9	371.1	7519.7	3765.1	3422.4
Axial diffusion area, cm²	464.6	438.9	403.6	9340.7	4227.4	3422.4
Radial slowing-down area, cm²	628.9	588.6	528.1	803.3	640.6	387.0
Axial slowing-down area, cm²	709.5	652.7	570.6	962.1	703.2	387.0

* Average U temperature, 425° C; average graphite temperature, 250° C.
† Thickness of reflector quoted.

Calder Hall | Metallurgical Development

METALLURGICAL DEVELOPMENT done during the course of the Calder Hall project is of interest both for the basic work on the physical metallurgy of magnesium alloy and uranium, as well as for the engineering development of materials for gas-cooled reactors.

Pressure-Vessel Steel

Standard pressure vessel techniques and materials could not be used for the Calder Hall pressure vessel; it is 37 ft in diameter, 70 ft high, and 2 in. thick. Fabrication of the vessel at the site is required. Thus the development of special welding techniques, inspection techniques, and stress-relieving treatment become necessary. This requirement of on-the-site fabrication may well be one of the main drawbacks of the reactor, especially for export.

Significant oxidation of structural materials occurs in CO_2 at the temperatures to be expected in the Calder Hall reactor. Data are given in Table 1. The samples were exposed at 400° C to CO_2 at 8 atm pressure, with varying moisture content. It is interesting to note that moisture almost doubles the corrosion rate.

Other important considerations are:

1. The steel should not be susceptible to brittle fracture at temperatures attainable during erection or during a shutdown period.
2. Creep may affect charging-mechanism alignment.
3. The long-term creep-rupture properties of the steel should be sufficient to give an adequate safeguard against fracture at low ductility.
4. The presence of loose scale on steel plates is obviously undesirable.

The steel finally selected for application was a fine-grained, low-alloy material (0.14% C,1% Mn).

Uranium Fuel Slugs

Both the requirements and the final technology used to solve the problem differed markedly from the standard practice in the U. S. The original requirement was for U bars 4 ft long and 1.15 in. in diameter. The bars are stacked end to end in a 20-ft vertical array. The obvious problem is that of bowing in service, which depends, in turn, on the straightness and freedom from radiation damage of the individual bars. The original length was reduced to 3½ ft in order to overcome these mechanical difficulties. The prime requirement becomes one of producing sound bars of this shape.

The techniques simultaneously investigated were rolling and welding together of shorter rods, along with casting. In the Reactor Handbook, vol. 3, p. 401, ff, techniques for the forming and fabrication of uranium metal are given. Extrusion and rolling are the techniques on which most effort has been concentrated. The possibility of casting to shape is not even considered. For the Brookhaven reactor (Reactor Handbook, vol. 2, p. 455) the U was cast and then extruded. The bars were then straightened and machined. After the machining, they were heat treated at 600° C, cooled and then machined to final dimensions.

The British have evidently developed acceptable rolling and welding techniques, but chose to use a casting process on economic grounds. The molds used were graphite with a parallel development of chromium plated steel. Evidently, the graphite mold was the preferred method.

Early in the program, the decision was made to go to a random fine-grained U structure on grounds of dimensional and surface stability. After cooling of the as-cast bars, high-frequency induction heating of the metal was used to permit the quickest possible heating, and consequently to limit surface oxidation.

The annealing temperature and time and the U purity are not given. In reply to a direct question it was stated that these are to be considered as "private" for commercial reasons. The statement was made however, that all three are extremely closely related. The heating time is probably quite short with the temperature well up in the beta phase of uranium (over 660° C) The oxidation produced by the annealing process is so slight and the heat controlled so well that bars may be annealed either before or after final machining.

Some of the bars produced were bent, and consequently unacceptable. Cold pressing, hot and cold stretching, and annealing were tried under various loads, but in all cases the curved condition would be restored under thermal cycling. In one experiment, a bent U bar was straightened and put into a heavy austenitic-stainless-steel tube and heated to a temperature at which the uranium was expected to be stress-

ENDPRODUCT OF METALLURGICAL DEVELOPMENT. Finned fuel elements await use at Calder Hall

relieved. On removal the stainless-steel tube was found to have bent to the shape of the U. The final cure for the bent-bar problem was extremely careful control over all of the manufacturing process with particular emphasis on the alignment of the induction heaters. Straightening of crooked bars has evidently been successfully attempted in the U. S., at Hanford. The reasons for the apparent discrepancy in technique are not known.

Fuel Cans

A number of different canning materials were investigated. Physical properties of possible canning material are given in Table 2. The most important requirements are

- Low thermal-neutron cross section
- Good resistance to coolant attack
- Compatibility with U under operating conditions
- Good sealing characteristics
- Resistance or accommodation to stresses imposed by the fuel during operation. This implies good ductility combined with adequate strength
- Good thermal conductivity and extended coolant surfaces for heat transfer

Much early work had been done on the use of aluminum for canning materials. The Windscale reactor fuel elements were Al clad. Oxidation tests on magnesium, however, indicated the possibility of satisfactory operation up to 400° C in air. As may easily be seen from Table 2, the nuclear properties of Mg are substantially better than those of Al, with only a very small decrease in thermal conductivity. Even though satisfactory operation of pure Mg canning in CO_2 appeared possible without fire hazard, it was felt that an alloy which would be oxidation-resistant at temperatures up to and including the molten state would be a substantial advantage. Magnesium alloys containing 0.05% Be, 0.1% Ca, and 1.0% Al were developed; they are remarkably oxidation-resistant. Tests in wet CO_2 with magnox E alloy showed no failure in 2,500 hr at 615° C.

The alloy finally selected for reactor canning was magnox C, in which the Ca was omitted. Difficulties in welding due to cracking and poor penetration were relieved by the omission of the Ca, and the loss in oxidation resistance was insignificant in CO_2.

A remarkable property of magnox alloys is their extreme sensitivity to certain metallic contaminants. A list of some of the contaminants and the temperature at which complete can penetration can be expected follows:

Mercury	All temperatures
Tin	Above 200° C
Lead, bismuth	Above 250° C
Cadmium, zinc	Above 300° C
Aluminum, calcium	Above 400° C
Silver, copper	Above 450° C
Nickel	Above 500° C

It is thus apparent that strict cleanliness with respect to metallic contamination must be observed during all phases of the handling of Mg alloys.

A very important characteristic of Mg alloys is, however, that they do not form any intermetallic compounds with U metal, and consequently no barrier between the U and the Mg is required. This property will simplify the canning process enormously and consequently result in a substantial reduction in fuel-element-fabrication costs.

Even though Mg alloys are known to corrode in natural water, shielding for handling is provided by open-water ponds. It was decided that although some increases in pond activity can be expected from corrosion and possible penetration of the cans, the pond activity will probably not rise to a dangerous extent. The present practice is to strip the can from the fuel element under water, with provisions made for the eventual safe discharge of pond water.

The lack of a metallurgical bond between the can and the uranium leads to the curious behaviour called "ratcheting." Differential thermal expansion of the U and Mg causes an elongation of the magnesium that does not disappear as the temperature is cycled. To prevent the ratcheting the bar of U is made rough intentionally and the can is pressure bonded on to the roughened bar.

Significance for Others

The application of the U and Mg metallurgy developed here is limited by corrosion and temperature. Magnesium alloys could not be used in aqueous systems because of the corrosion problem. The limiting operating temperature of the uranium metal will be that of the alpha-beta phase change at 660° C. Consequently the only application of the system to reactor technology apart from the Calder Hall reactor would probably be in air-cooled research reactors of the Brookhaven and Oak Ridge type.

TABLE 2—Physical Properties of Canning Materials

	Beryllium	*Magnesium*	*Zirconium*	*Aluminum*	*Niobium*
Thermal neutron absorption cross section $10^3 \sigma$ abs. cm²/cm³	1.23	2.54	7.65	13	59.9
Melting point, ° C	1,284	650	1,860	659	2,415
Thermal conductivity at 125° C, B.T.U./hr ft ° F	80–64	95.76	10.08	133.56	32.76
Vapor pressure	Low	(High 1 μ at 400° C, 100 μ at 500° C)	Very low	Very low	Very low

TABLE 1—Oxidation of Materials in Carbon Dioxide

Material	*Oxidation*
18/8/1 stainless steel	Excellent (No measurable attack after 5 mo)
Commercial Al	
Sintered Al powder	
Pure Mg	Good (0.1 mg/cm²/5 mo)
Magnox C	
Mg alloy AM503	
Al alloy RR58	
Al alloy RR57	Moderate (0.15 to 1.11 mg/cm²/5 months)
Mg alloy ZT1	
Mg alloy ZRE1	
Magnox E	
Alloy steel (Jessops G1)	
Mild steel (0.05% C)	
Sintered Mg powder	
Pressure-vessel steel	
Heat-exchanger steel	
Cast iron	2.72 mg/cm²/5 mo

Calder Hall | Heat Transfer

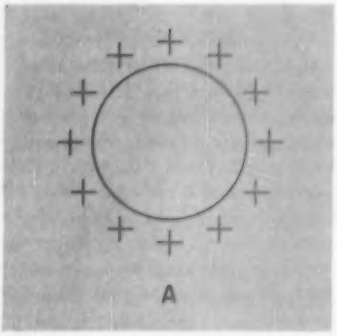
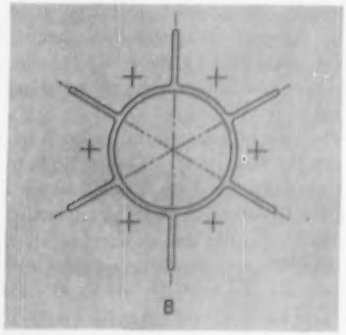
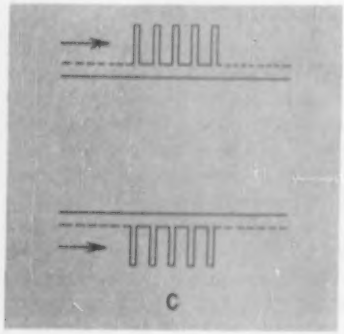


FIG. 1. Finless X10 elements . . .



. . . Brookhaven added longitudinal fins . . .



. . . Calder Hall uses these transverse fins

IN ALL REACTORS, but particularly in gas-cooled reactors, the heat-transfer considerations are governing in over-all design. In natural- and low-enrichment-uranium gas-cooled reactors the fuel must be lumped in order to avoid excessive U^{238} resonance neutron capture. The optimum fuel element in nearly all natural-U reactors turns out to be cylindrical with 1–2-in. diameter. On the other hand, for gas cooling the maximum heat removal is limited by the surface area of the element. For heat-transfer purposes it would be desirable to have as large a ratio of surface to volume as possible. Therefore, the concept of extended surface for heat transfer becomes relevant to heat-transfer design.

Transverse Finning

Perhaps the most novel aspect of the Calder Hall reactor consists of the use of transverse finning on the fuel elements. The evolution and development of transverse finning is schematized in Fig. 1. The earliest gas-cooled reactor fuel element was that for the Oak Ridge graphite reactor. This fuel element was a simple cylinder in shape, clad with aluminum, and it had no extended surface. The second sort of configuration is longitudinal finning, as used in the Brookhaven graphite reactor, as well as in the Windscale production reactor in Great Britain. The third step in development is transverse finning, which apparently can be made to give the greatest heat transfer for a given pressure drop in the coolant channel. It should be noted, however, that the Calder Hall reactor uses magnesium alloy as a canning material. This alloy has a substantially lower cross section than does aluminum, and consequently a greater amount of heat-transfer extended surface is permissible for a given parasitic neutron capture.

Windscale experience. The necessity for the improvement in heat trans-

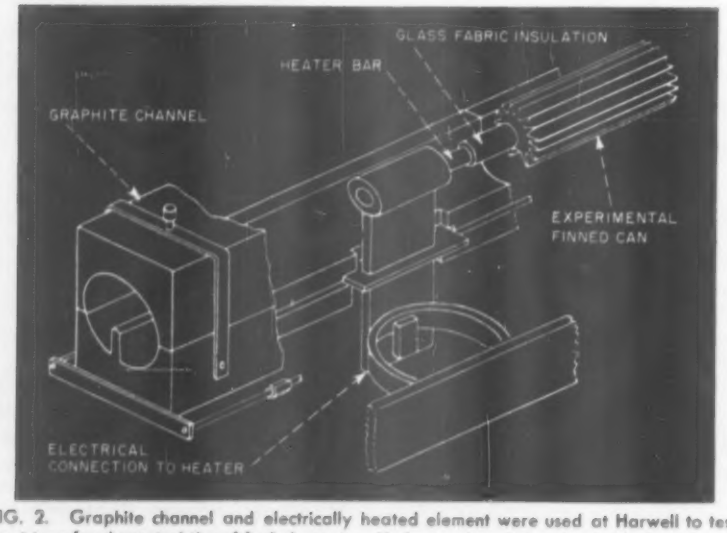


FIG. 2. Graphite channel and electrically heated element were used at Harwell to test heat-transfer characteristics of fuel elements. Under test here is longitudinally finned can

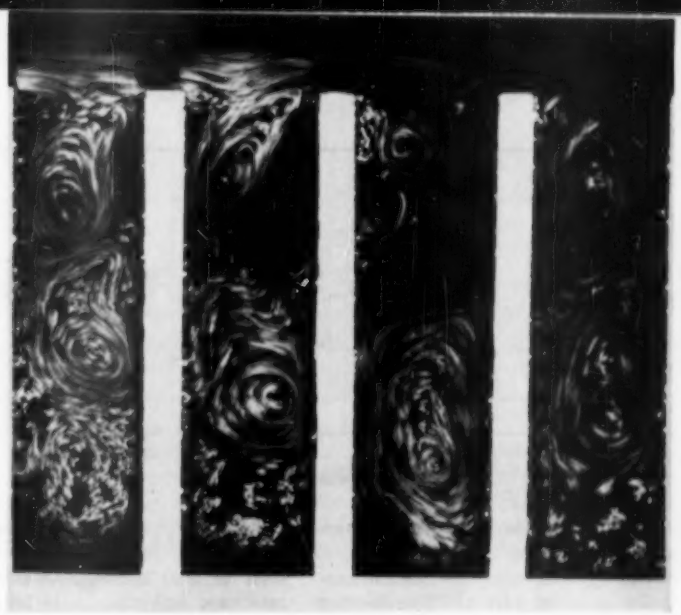
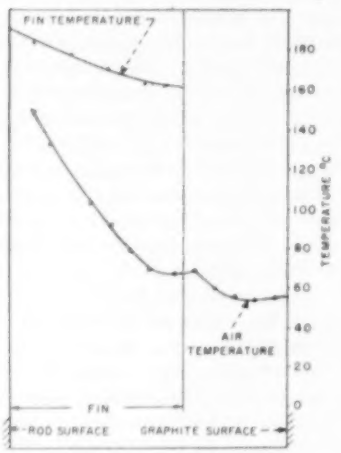


FIG. 4. Surprisingly good heat-transfer characteristics of transverse fins are probably explained by better-than-expected sweeping by the coolant. Photographs indicate that basic flow pattern has two coupled vortices between each pair of fins

FIG. 3. Typical fin and air temperatures for elements with longitudinal fins



fer of longitudinally finned elements arose when experimental heat-transfer coefficients proved about 30% smaller than predicted. Predicted values were based on the assumption that the finned can-and-channel assembly could be considered as a tube of the same effective hydraulic diameter (Fig. 2).

Detailed experiments were conducted to determine the cause of the discrepancy between the predicted and experimental data. The typical distribution of fin and air temperature for longitudinal fins is shown in Fig. 3.

Devices to promote mixing were also investigated experimentally. The most successful of these is a ring around the element perpendicular to the coolant flow. These turbulence promoters were used in the central portion of the Windscale reactors in an attempt to increase the heat transfer in the center of the reactor.

Experiments

The use of transversely finned elements at first seems fairly unreasonable. One would imagine that very little gas would get down between the fins, and that a substantial amount of turbulence would be generated, resulting in an excessive pressure drop. Experimental data has shown, however, that the heat transfer is surprisingly efficient when compared with a longitudinal fin (Fig. 4).

It is apparent that no modification of present heat-transfer correlations would serve for the prediction of heat-transfer coefficients. Extensive measurements were made for the ranges of surface being considered for the Calder Hall reactor. However it should be noted that these tests cover a very limited variation of the experimental parameters. A heat transfer correlation is given in the form

$$St = \psi\left(Re, Pr, \frac{k}{k_m}\right)$$

Where St is the Stanton number, Re is the Reynolds number, Pr is the Prandtl number, k is the thermal conductivity of the gas, and k_m is the thermal conductivity of the fin material.

This correlation could serve for the preliminary consideration of transverse finning in other reactors, but experimental testing of the heat transfer is extremely desirable.

The experimental data on transversely finned elements was obtained on two setups. The first provided for measurement of heat transferred from heated elements to circulating gas.

The second apparatus was pressurized to allow the heat-transfer experiments to be carried out in a gas other than air, under pressures up to 100 psi. The data obtained in the air-cooled apparatus do not correspond to the reactor, in that a Reynolds number of 2.5×10^5 was achieved while the reactor operates at a Reynolds number of 3.5×10^5. The corresponding Mach numbers are 0.29 and 0.062.

A comparison of the experimental results for transverse finned rods and

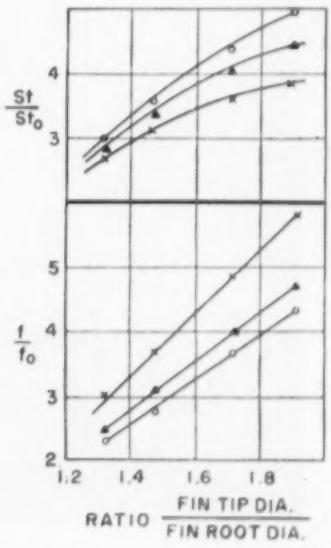


FIG. 5. Both Stanton number and friction factor increase with size of fins with transverse finning. Circles are data for $\frac{3}{16}$-in. fin pitch; triangles for $\frac{1}{4}$-in.; x's for $\frac{3}{8}$-in.

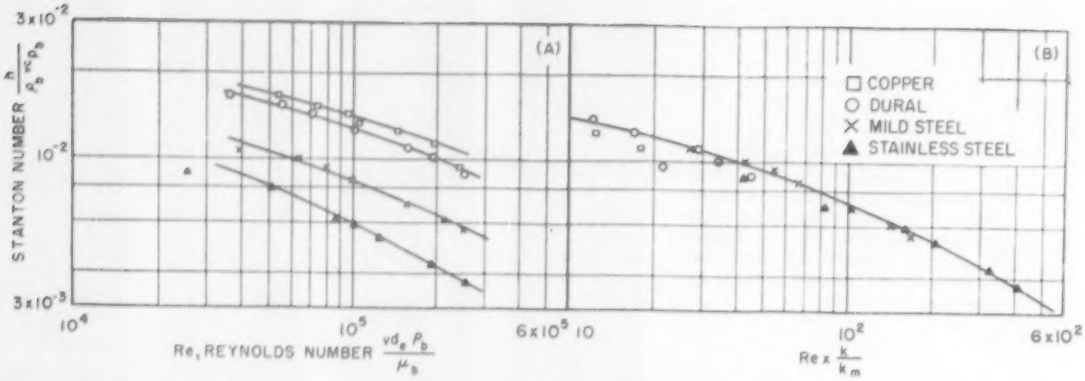


FIG. 6. Data for heat transfer in transverse fins of four materials (A) fall together when plotted as shown in B

for solid rods of the same outside diameter is given in Fig. 5. The Stanton number, which is proportional to the heat transfer coefficient for the finned rod, is shown to be substantially higher than the Stanton number for the solid rod. However, it should be noted that the friction factor, which is proportional to the pressure drop in the coolant channel, is also larger for transversely finned rods.

In order better to understand the mechanism of heat transfer from transversely finned elements, experiments were carried out with fins of varying thermal conductivity. Copper, duraluminum, mild-steel, and stainless-steel fins were used. The experimental values for the Stanton number are shown in Fig. 6.

To correlate the data, points were replotted against the Reynolds number times the thermal conductivity of air, divided by the thermal conductivity of the fin material. It can be seen that a fairly good correlation was achieved.

Using the pressurized apparatus, heat-transfer experiments were run for CO_2, nitrogen, and helium. The data are shown in Fig. 7. Using the Reynolds number as modified above, the data were replotted and a fairly good correlation obtained as shown in the figure.

Significance

In assessing the value of this transverse finning technique for high-temperature (~1,100°–1,500° F) reactors working with a closed-cycle gas turbine, or a heat exchanger generating high-temperature steam, the most obvious conclusion can be drawn from Fig. 6. Copper, duraluminum, and similar high-conductivity metals are not much good for high-temperature application, and materials such as stainless steel, which are acceptable for fuel elements, will result in substantially poorer heat transfer for a given pressure drop, using this type of extended surface.

Nitrogen and carbon dioxide are relatively poor gases as far as thermal conductivity is concerned. Helium has good heat-transfer properties and good chemical properties and thus is likely to be used as a working medium for high-temperature gas-cooled reactors. However, it can be seen directly from Fig. 7 that the effectiveness of finning for a given Reynolds number is substantially less for helium than it is for gases such as CO_2 and nitrogen.

Without carrying out detailed calculations, for specific reactors, it is impossible to predict that the transverse finning will have no role in high-temperature–gas-cooled-reactor technology. However, on the grounds given above, it seems at this time to be somewhat unlikely. Transverse finning could provide a means of improving the power output of air-cooled natural-uranium research reactors operating with high-conductivity canning materials. However, since the heat transfer can not be considered without simultaneously considering the change in nuclear characteristics caused by the increased amount of parasitic neutron absorption, no firm statement as to the usefulness of transverse finning for this application can be made at this time.

The data given from the experimental investigation are not sufficient to allow a reasonable prediction of the usefulness of transverse finning in reactors cooled by liquids. New experimental investigations will be required.

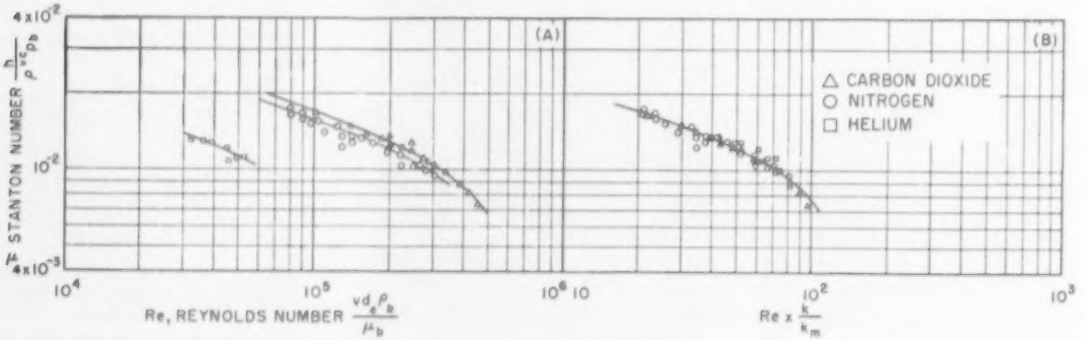


FIG. 7. As in Fig. 5, data for heat transfer with different gas coolants fall together when replotted vs $Re \times k/k_m$

Calder Hall | Blower Seals

THE GAS-BLOWER SHAFT SEAL at Calder Hall is designed for minimum gas leakage. A compressor of the rotary centrifugal type was designed with an overhung impeller in order to eliminate the necessity for bearings within the reactor coolant gas. The seal used is a modification of existing seals used on hydrogen-cooled generators. Consideration was also given to packed labyrinth-type seals, dry rubbing seals, and gas bearings. But on the basis of early successful experiments the present seal was selected.

The basic requirements for the blower seal are as follows

1. The seal must be capable of being renewed or serviced without disturbing the blower circuit.
2. Diffusion of oil vapor into the active system must be prevented.
3. Liquid oil must not be allowed to get into the active system under any conditions.

The over-all seal is shown in the figure at right.

The seal itself is obtained by the rubbing of a hard nitrided surface against a stationary white-metal ring. The seal is lubricated by a very small flow of oil (1 gal/hr through *1*). Since a substantial amount of heat will be generated in the seal, coolant oil is needed. Nearly all of the oil flowing through channel *3* is directed towards the outside through channel *2*. By regulating the width of channel *2* and the oil pressure, the oil flowing through channel *1* can be controlled.

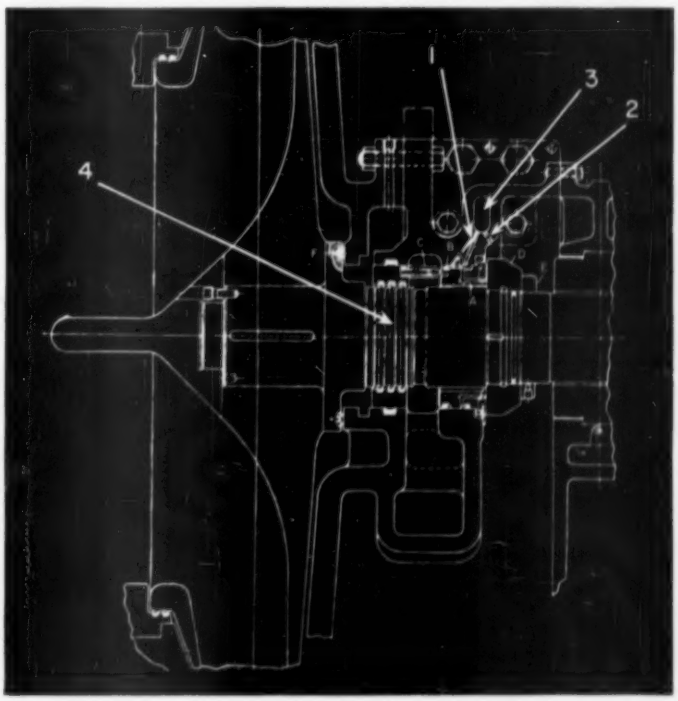
The stationary ring is spring-loaded to provide a fixed force against the shaft. The 1 gal/hr of oil flowing through *1* is collected in a detraining tank and the dissolved CO_2 separated out. An additional labyrinth seal *4* is provided to prevent any oil vapor from diffusing back into the active system.

It appears that CO_2 is soluble in oil to the extent that there is a small flow of CO_2 out of the system through the labyrinth seal and into the 1 gal/hr of oil flowing through channel *1*. Under full pressure and temperature conditions, the quantity of CO_2 absorbed by the oil and released to the atmosphere is about 5 lb/day. By using a fully sealed detraining system it would be possible to cut this loss down to zero in the event that the coolant gas were highly active.

If it were desired to seal a gas other than CO_2 it would be necessary to investigate the solubility of the gas in the oil since total lack of solubility might cause oil vapor to diffuse backwards into the system.

The detailed design of the seal (Fig. 1) shows that the seal can be repaired with the system at pressure. By moving the entire impeller shaft to the right, seal *F* comes into contact with the frame of the blower. The pressure in the seal compartment can then be reduced to atmospheric with no loss of system gas. The effect of the system pressure will be to hold seal *F* closed. The seal itself can then be repaired or replaced without any further loss of system gas.

The seal to be used on future reactor developments will probably be of the gas and oil type depending upon shaft rotation dragging along the oil or gas and building up a pressure to counteract system pressure.



BLOWER SHAFT GAS SEAL. Floating ring *A* fitted with two U-type rubber packing rings *B* is located on a spherical seating in the bottom half of the circulator casing to which is bolted the keep. It is spring-loaded *C* against a loose collar *D* keyed to the shaftand held by a nut *E*. Rubber 'O' ring seals gap between loose collar and shaft. Collar has nitrided face whereas floating seal ring, which is $\frac{1}{16}$ in. eccentric to the axis of the shaft, is faced with white metal

Calder Hall | Burst-Slug Detection

Each of the 1,696 channels of the Calder Hall reactor is sampled at regular intervals to ascertain if any of the fuel-element cans have sprung leaks and are releasing fission products into the CO_2 coolant stream. The detection method relies on the precipitation onto a wire and counting of the radioactive daughters of gaseous fission products principally krypton and xenon. The over-all system is of considerable complexity, involving some 40 miles of sampling tubes and eight 54-way sampling valves as well as ten sensitive counting stations. Being the first of its kind, the detection system is undoubtedly overdesigned, but, by the same token, it is an instructive example of how the burst-fuel-element problem can be met in gas-cooled reactors.

Channel Sampling

Each of the 1,696 reactor channels has an individual ½-in. stainless-steel sampling pipe that passes through the pressure-vessel wall, through the shields, and into the room where the counting stations are (see Figs. 1 and 2). This is done in 8 groups of 212 channels each and a separate faulty-fuel-element detection system is provided for each group. In the detection room the 212 sampling tubes are joined by headers in fours to form 53 subgroups. Immediately preceding the headers are individual manually operated two-way valves to allow for the switching of any one of the four channels to a separate detector for additional scrutinizing when it is called for.

Timing. The 53 subgroups are sampled in turn by an automatic 54-way selector valve; the extra position being provided for standardization. A new position is selected every 33 sec and thus there are 30 min between samplings from the same group of four.

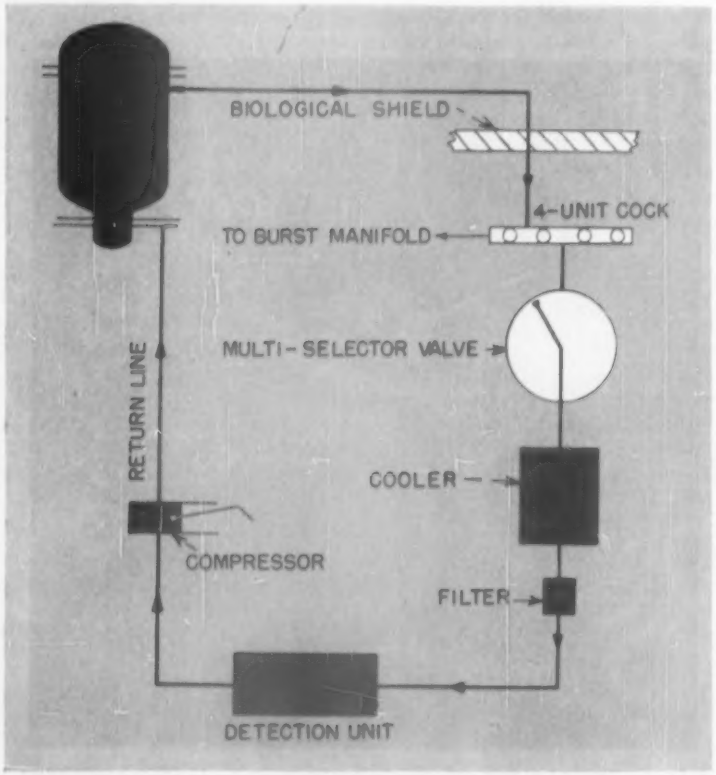


FIG. 1. Simplified flow diagram shows path of sampling pipe out of reactor vessel and shields to 4-unit header then, when selected by 54-way valve, to cooler, filter, and detection unit (shown in more detail in Fig. 2). Compressor is of the carbon-ring type having no lubricated parts in contact with the gas. Failure to compress gas and return to main circuit would cost about $700,000/yr in CO_2

Detection Units

The brains of the burst-fuel system are the ten identical detection units, shown schematically in Fig. 3. Each consists of two main sections, the precipitation chamber and the counter assembly. The entire unit is operated at a little below reactor-outlet pressure and therefore is enclosed in a cylindrical pressure casting.

Precipitator. Sample gas that has been cooled (to eliminate thermal effects on the scintillator that follows) and filtered (to remove any solid fission products) sweeps into the precipitation chamber. The precipitator consists of a 5-mil grounded center wire surrounded by a shell at 4 kv. The resultant electrostatic field causes ionized particles within the gas to deposit on the center wire. If there is a leak in one of the fuel elements in the channels being sampled the Rb and Cs daughters of fission-product Xe and Kr that passed through the filter will be present and will be precipitated out, to reveal their existence in the counting unit that follows.

Counting unit. After a 30-sec precipitation period the wire is advanced

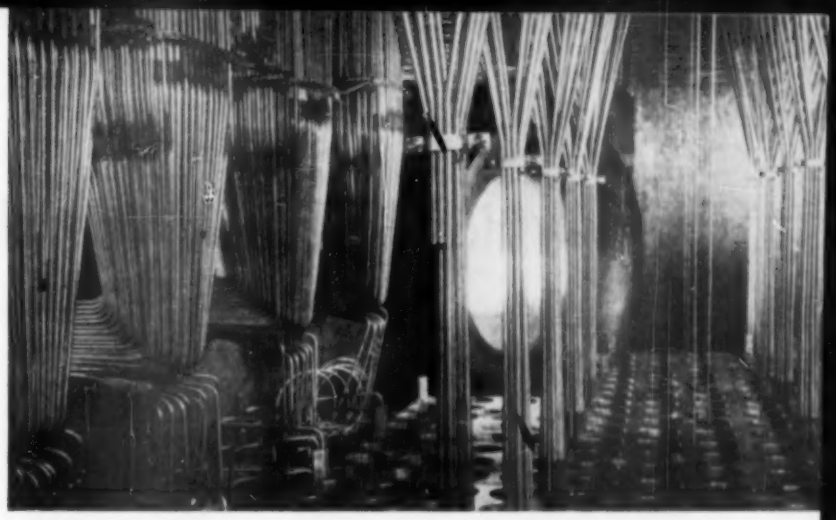


FIG. 2. Following labyrinthian path within reactor vessel, sample piping rises out of corners of charging pans and fans out into a plane to give clearance for control-rod drives and fuel-loading equipment. Piping exits from reactor vessel in groups of 212 through eight header plates. Note at left ferrules used to join sections of stainless-steel pipe; these contain brazing metal. Leakless joint is made on the spot by induction heating

by a motor drive out of the precipitator section and into the counting unit. There it is automatically centered with respect to a cylindrical scintillator having an axial hole through which the wire passes. The scintillator is made of polystyrene in which is dissolved tetraphenyl butadiene; its outside diameter is about 2 cm, the optimum size for detection of Cs and Rb betas rays. Any increase in outside diameter would only increase the sensitivity to background gamma rays.

For support and gas-tightness the scintillator is set in Lucite, using Araldite to insure good optical properties. The whole is viewed by a photomultiplier placed outside the pressurized detection unit. Local shielding is provided by a cast-iron plug.

Sensitivity

The sensitivity of the burst-fuel-element detection system is such that a 4-mm² hole in a fuel element in the center of the reactor will double the background counting rate. For fuel elements located elsewhere it takes a bigger hole to produce the same result —seven times bigger in the extreme case of a fuel element located in an outer channel. This variation stems principally from the variation in gas flow and neutron flux in the various channels.

Background. The principal source of background in the detection system arises from small deposits of uranium on the fuel-element cans. (This uranium is of course indistinguishable from uranium released by can failure.) Typically there will be of the order of 50 micrograms of uranium thus exposed per channel—this in spite of the most stringent cleaning efforts. This amount of activity gives rise to about 100 cps in the detector head per channel, or, since four channels are sampled simultaneously, to approximately 400 cps. It is this counting rate that is doubled by a 4-mm² hole in a central fuel element.

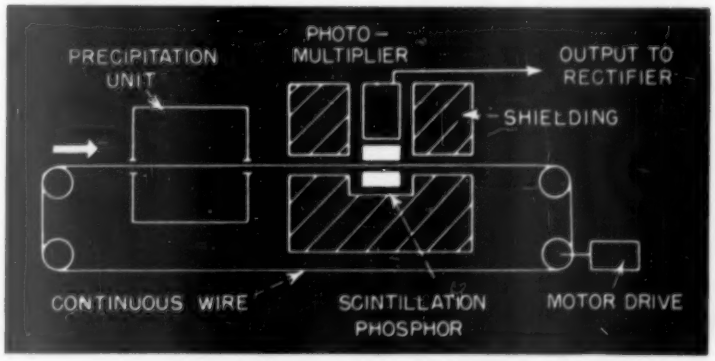


FIG. 3. Burst-fuel detection head counts activity precipitated onto 5-mil wire. Principal activity on wire decays with 6-min half-life; wire must be long enough to have decayed substantially by the time it is due to be counted again. With passage of time, long-lived activity builds up and requires replacement of wire, a simple chore

There is a background contribution from cosmic rays and reactor gamma rays, but this is much less than that just discussed, and is further reduced (by a factor of two) by local shielding. Background due to activity of the coolant itself is virtually eliminated by a slow purge of virgin CO_2 in the vicinity of the phosphor—most of the CO_2 in the precipitator is excluded by a seal on the sample-bearing wire.

Readout

The state of the 54 groups of 4 channels monitored by any one detection unit is indicated compactly by means of a special 9-pen recorder (Elliott Co. ND51). A 6×9 matrix yields a $1\frac{1}{2}$-in. square as the area in which to record 24-hours' behavior for each 4-channel group.

These small graphs are merely intended to give the initial warning; when a high count is confirmed the information from the suspect channel can be diverted and presented alone on a single recorder, thus providing an accurate record of the progress of the suspected burst.

These recorders are located in the reactor control room along with alarm circuits for high count. Additional alarms are provided at the detector unit for precipitator voltage, gas flow, temperature, wire drive and breakage, and gas leakage through the drive seal.

Using the manual valves provided, the outputs from the four suspect channels can be switched individually in turn to the standby detection unit and the particular faulty channel identified. The system does not identify the particular fuel element that is leaking, only the channel, thus the entire channel must be discharged to insure eliminating the offender.

Calder Hall | *Fuel Handling*

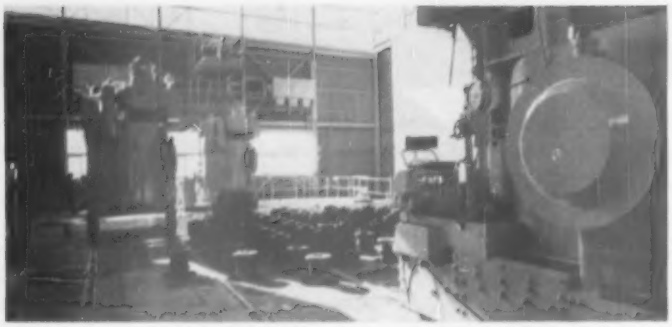
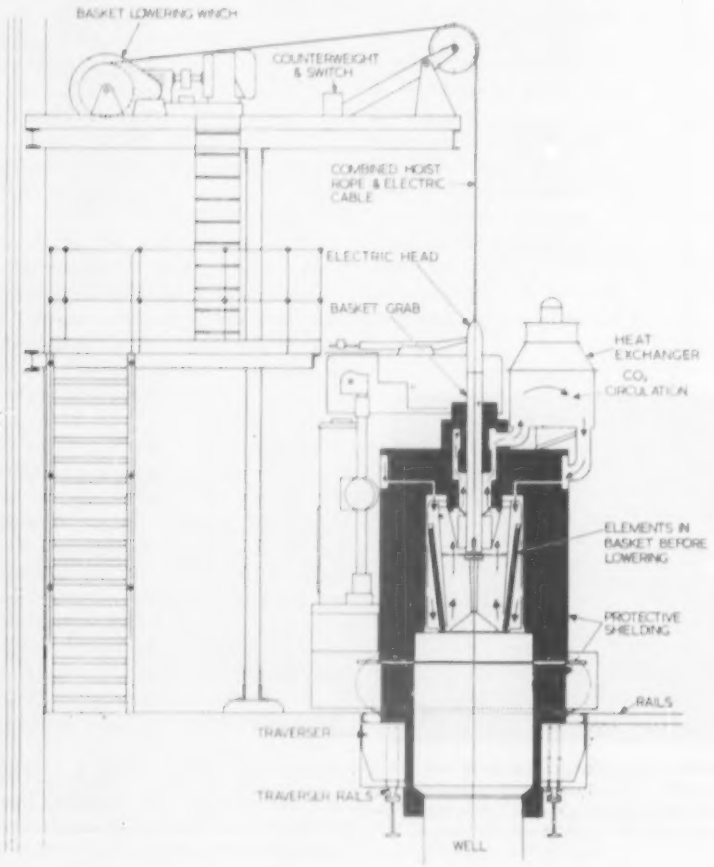


FIG. 1. Charging floor above concrete shield holds two heavily shielded discharging machines (one shown extreme right) and two lightly shielded charging machines (left). Machines can drop grapples through chutes to pick up or deposit fuel elements as illustrated in Fig. 3



A SIMPLE AND ELEGANT handling technique is used for refueling the Calder Hall reactor. The possibility of reloading under pressure, which would eliminate reactor shutdown, was considered and rejected because of its complexity. The present design is simple with no moving parts in any section subject to radiation. All the equipment can be easily repaired. Manual and semiautomatic control is used, eliminating the need for a complex automatic control system. Before refueling, coolant pressure is reduced to about 2 psig. The possibility of carbon dioxide escape is considered preferable to having air leak into the system. Coolant is circulated to maintain a temperature of about 150° C at the outlet end of the reactor. There are 106 openings in the top of the reactor, each serving 16 fuel channels (Fig. 1). Thus the total number of pressure-vessel penetrations is reduced.

Chute-and-Grab System

The fuel-element grab contains a bayonet-type lifting head and an electromagnetic torque motor that causes it to grab the three-pronged spider on top of each fuel element. The hoist cable and electrical connection are run coaxially in the same cable for simple operation. Spent fuel elements are lifted through chutes into a CO_2-cooled discharge basket that has spaces for 24 spent elements. A cross section view of the basket in the discharge machine is shown in Fig. 2. When the basket is full, the discharge machine is rolled over to a well and the basket lowered into a four-wheeled shielded transit

FIG. 2. When basket of discharging machine is loaded with irradiated fuel elements, it is rolled to traverser at end of floor. Traverser then moves over well through which basket is lowered for removal

vessel. The vessel is then driven to Windscale for eventual reprocessing.

The charging machine is similar to the discharging machine, but the shielding is omitted since unused elements are not radioactive. Twenty-four elements are stacked in a basket and lowered down a chute in the reverse of the discharge cycle. Since separate machines are used for charging and discharging, both operations can be carried out simultaneously. This ensures minimal reloading time.

Figure 3 shows a fuel-element chute inserted through the shield into the pressure vessel. Rubber gaskets keep carbon dioxide from leaking to the atmosphere. Three radial settings of the chute permit access to 16 channels. A simple manual mechanical control mechanism is used for radial and angular setting of the chute, and a mechanical indicator shows chute location.

Trouble Shooting

Provisions have been made for trouble shooting and repair. A general-purpose vessel with a lead-glass window and special equipment for operation by manual techniques is used for removal of faulty fuel elements. This avoids contamination of the discharge machine. If a fuel element is jammed, a special TV camera is used to examine the nature of the difficulty (NU, May '56, p. 110). The outside diameter is only 3½ in. The camera contains its own light source and a remotely operated viewing mirror. It is internally cooled by cold CO_2 so that it can be operated in ambient temperatures up to 200° C (Fig. 4). CO_2-operated grabs and removal tools are then brought into play as required by the specific difficulty.

Future Developments

It is reported that all of the four industrial groups doing advanced Calder Hall design are departing from the practice of shutdown refueling and provide for reloading under pressure. This is important because the high capital cost of the Calder Hall type of reactor dictates the use of a high load factor and minimum down time. A further reason is that fairly sophisticated methods of fuel-element cycling will be employed to minimize the amount of control-rod insertion and consequent flux distortion. Fuel-element cycling requires fairly frequent fuel-element changes, which are impossible except by reloading under pressure.

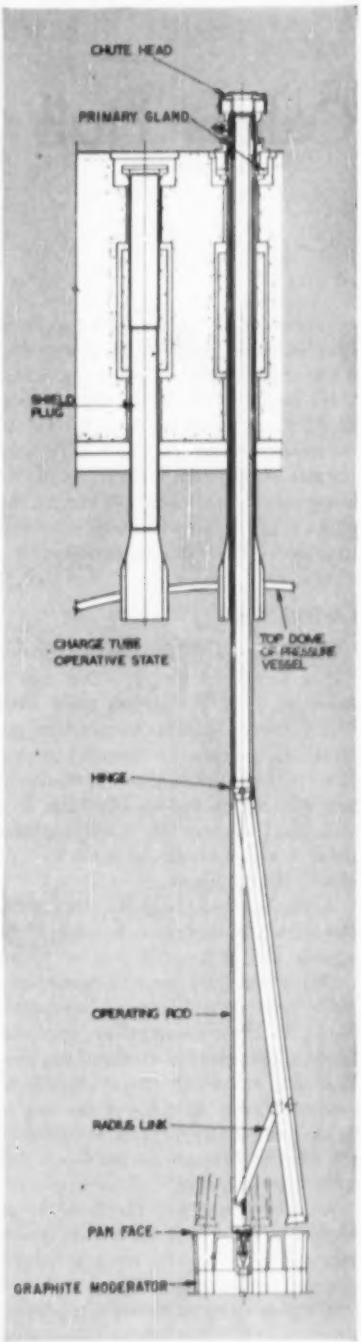


FIG. 3. Metal standpipes welded to pressure vessel extend up through 106 holes in concrete shield. Hinged chute dropped through one of them reaches 16 adjacent fuel channels by pivoting and radial extension. Grapples of charging and discharging machines reach fuel elements through chute to remove fuel elements and replace them ▶

◀ FIG. 4. Remotely operated TV camera drops into fuel channels for inspection of faulty elements. Optical focus is remotely adjustable from 3 in. to 3 ft. Instrument is normally end viewing, but solenoid operated mirror and turret rotation permit sideways viewing too

Calder Hall | Control Rods

CONTROL of the Calder Hall reactor is effected by a system of 60 coarse and 4 fine control rods. These rods have a total negative reactivity contribution of 5.5%. Of this 4.5% is needed to overcome excess reactivity built into the reactor to compensate for reactivity changes with operation (see Fig. 1), the other 1% is to cover contingencies and provide for more rapid shutdown.

Control Rods

The general arrangement of a control rod is shown in Fig. 2. The sheath tube, of 18/8/1 stainless steel with 0.02% cobalt content (to minimize activation), is primarily intended to contain any particles of absorber that may rub off. Since the sheath tube is a structural member, the absorbing material, boron steel, can be in the form of short tubular inserts.

Assuming that the reactor is always run with the control rods inserted to absorb 1% in k, 10% loss of boron would occur in 20 years; hence ¼-in.-thick tube of 4% alloy is adequate. Since, on these assumptions, only the bottom few feet of control rod are continuously in the core it was possible to grade the wall thickness of the inserts from ¼ in. at the bottom to ⅛ in. at the top; furthermore, at the top, a 3% alloy was adequate.

As shown in Fig. 2 the cable is attached to the top of the rod in such a way that its removal from a remote position is relatively simple.

A spring shock absorber is provided, which supports the rod in the normal lowered position, with the top resting on the charge pan. In normal operation, including emergency shut-down, the terminal velocity of the control rod is less than 6 in./sec, and the spring cushions the final impact. Should the cable break, the force of impact on the charge pan is limited to 300 lb by shear pins; the rod then continues to fall, and its kinetic energy is absorbed by a broaching device at the bottom end of the rod.

The average heat generated in a control rod was calculated to be ½ kw/ft but a severe gradient of thermal-neutron flux may exist at the tip of a control rod. For this reason generous gas cooling was provided; also, the absorption of the rod tip was graded to minimize the flux gradient.

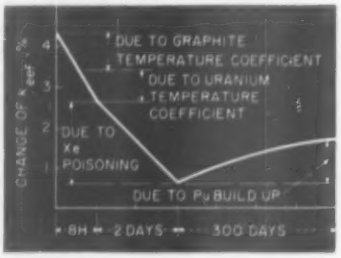


FIG. 1. Changes in k_{eff} with time

Control-Rod Drives

Calder control rods are suspended vertically by seven-strand stainless-steel cables. They are lifted by driving heads located above the top shield of the reactor, see Fig. 3; gravity return is used to lower the rods. The control-rod drives are powered by 200-w variable reluctance synchros operating as receivers from a common "transmitter" supply. Operating through 20:1 gears each synchro turns a drum on which the cable that supports the control rod is wound as a flat spiral.

Brakes. The shut-down specification requires a descent speed of 4 ft/sec, to be braked in the last 2½ ft to 6 in./sec. Thus the brake should have an 8:1 torque ratio between on and off. In addition, to act as a speed limiter, the brake must have a rising torque characteristic with speed.

Eddy-current brakes were used having Alcomax IV permanent magnets to provide 3,000 Gauss through a 0.090-in. mild-steel rotor disc electroplated each side with ±1 mil of copper. The flux is varied by a system of magnetic shunts programmed by a cam geared to follow the movement of the control rod. This produces a 9:1 variation of braking.

Clutch. A solenoid-operated clutch, excited in parallel with the drive motor is incorporated to avoid the need for the control rod to accelerate the motor during emergency shutdown. Because of the low gear ratio chosen, however, the required shutdown performance is still obtained even if the clutch fails to free itself.

Position indication. The control-rod cable passes over a pulley which, through step-down gearing, drives a 2-in. synchro transmitter one revolution for the full rod stroke. The receiver, in the control room, indicates the control-rod position with an accuracy of ±1 in. When the control-rod cable is in the no-tension condition, a micro-switch is closed to light a lamp in the control room.

Drive supply. To obtain the rates of reactivity change specified, alternating current at 40 volts rms and 0.0133, 0.13, and 1.3 cps is supplied to the motor. This very low frequency is generated as follows: an induction motor drives an alternator, which is coupled to a rotary convertor through a 1:1 differential gear box. A special feature of the rotary convertor is that it has no stator winding but a distributed rotor winding supplied from the alternator. If driven in synchronism with its supply, a steady d-c output results; at any other speed, the difference frequency is produced. Thus the speed added or subtracted at the differential gear determines the frequency. The difference speed is derived from a pilot motor, through a system of gearing selected from the control room.

The fine-control-rod supplies are large resistance-type potential dividers, whose output frequency equals the

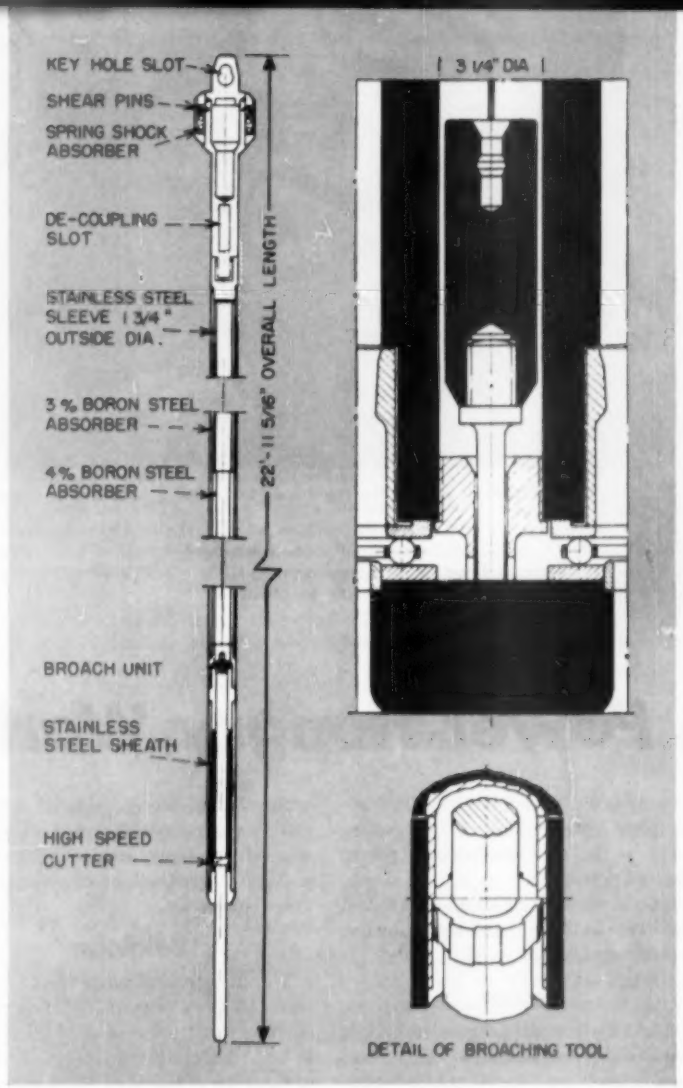


FIG. 2. Control rod employed at Calder Hall, impact stool at base of channel, and broaching tool

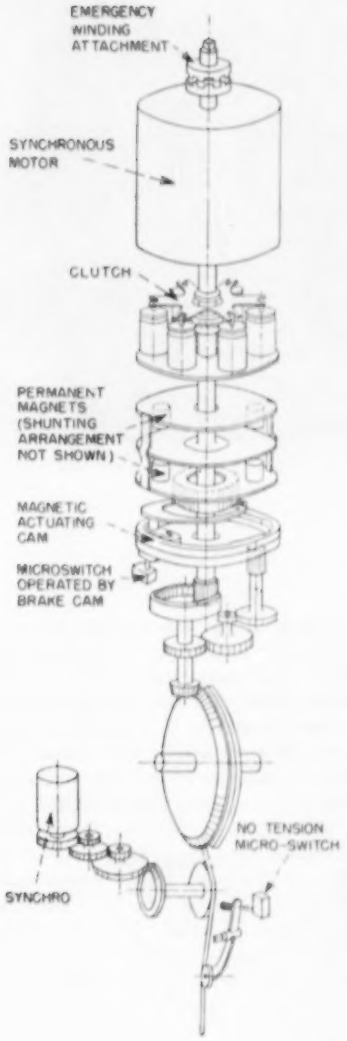


FIG. 3. Mechanism for driving control rods. Stainless steel cable at bottom supports rod (shown in Fig. 2)

speed at which the brush-arms are rotated by a mechanical linkage from the reactor control desk. The position of these rods follows the position of the handwheel on the control desk. Any four mechanisms may be connected to the fine-control-rod system.

Shield Plugs

As noted the control rod operates in the same tubes used for fuel loading (discussed on p. S22). Since a much smaller hole is required to pass the control-rod cable a plug is required to fill the excess space and provide a gas seal around the cable. The plug comprises a 4-in.-thick steel slab which acts as a thermal shield, and a concrete-filled cylinder divided into two vertical sections.

In addition to the cable-way through the plug a rod passes down to operate a flap at the bottom. This flap is forked to support the control rod when it is pulled out of its channel to detach the cable for charging operations. Mechanical interlocks ensure that the flap is brought into use before the control rod is pulled out of its channel, and conversely, that the flap is removed before normal operation.

Making Way for Fueling

The shield plug and mechanism must be removed before loading fuel through a charge tube. The reactor is not pressurized at this time, and after detaching the electrical connections at the junction box, the mechanism may be unbolted at the flange and removed for inspection. A rubber seal, which automatically closes round the lifting cable when the mechanism is raised off its flange, minimizes gas leakage. It would have been possible to design the charging operations to allow the control rod *and* lifting cable to remain in the reactor; however, it was decided to remove the cable each time for inspection. This is achieved by lifting the top of the control rod to the charge-floor level and detaching the cable by tools operated from behind shielding. It is not necessary to remove the control rod from the reactor.

ICHIRO ISHIKAWA, a full-time member of Japan's Atomic Energy Commission and head of a survey team to U. S. and U. K., discusses nuclear stations with an official of Mitchell Engineering Ltd. of London

DUTCH DELEGATES leaving the conference hall after a long day of conferring

A Power-Hungry World

LONDON on November 22 and 23 was a "little Geneva." As in 1955 at the Geneva atomic energy conference, representatives of a number of countries were "shopping." This time, however, there was only one vendor—the United Kingdom—and only one reactor type on view—Calder Hall.

At least 13 nations other than England sent men to the meeting: France, Sweden, Italy, Netherlands, Belgium, Norway, Spain, Denmark, Switzerland, Japan, West Germany, Czechoslovakia, and the U. S. Some were very strong prospects for Calder-type plants. Others were very much on the fence. And still others were merely seeking information.

Many of the countries represented had already been "approached" both by the Atomic Energy Authority and by the industrial groups. In fact, various British companies have submitted bids on large Calder-type plants to countries such as Japan, West Germany, Italy and Australia. There are two main appeals that Calder has for many of these countries: it's an operating reactor, and it uses natural uranium. The latter probably carries the greater weight because, even though the U. S. is making enriched uranium available at low prices, many nations don't want to tie themselves to any one country for fuel supplies.

A big disadvantage of Calder is that, at the moment, it is quite uneconomic in small sizes. And it is the smaller size plant—20–30 Mw—that is in demand in the countries seeking power reactors right now.

Here is why some nations sent representatives to the symposium, and what their interest in Calder Hall is:

Japan

One of the principal targets of British —and U. S.—sales efforts, Japan had only a few people at the meeting. However, one of several study teams that has been travelling abroad looking into various nuclear power schemes had just left the country after having been wined and dined by prospective vendors much as in the U. S. several weeks earlier. Although there has not yet been any announcement from the U. K. or Japan, there is now strong indication that the Japanese are favorably inclined towards a Calder-type unit. While in the U. S., the Japanese said they had received an offer from the U. K. of a 100-Mw plant for $38-million.

Spain

This country has already bought two small research reactors and now expects to buy, by next spring, a small power reactor in the 20–30-Mw range. Thus Calder Hall is too big for them. They're actually looking quite seriously at U. S. pressurized and boiling water reactors. However they did send a team of technical people to the London symposium to size up Calder. Because there was no discussion at the meeting of current designs, they said they were not able to get the kind of picture they were looking for.

Belgium

The Belgians recently made a decision to work towards building a fast reactor. But prior to this, they want to build a large thermal-neutron plant, of the order of 100 Mw. And so they're quite interested in Calder Hall. The thought they expressed at the meeting was that they doubted they would buy a complete plant, but rather would depend mostly on the U. K. for information about Calder.

France

There were about 15 representatives of French industry and as many from the French atomic energy commission. Design of the French plant G-2 due to come into operation late next year is very similar to that of Calder Hall, and for that reason the French were extremely interested in the problems the British have encountered with their gas-cooled graphite-moderated unit. Although the French are working with somewhat higher pressures, they are aiming at a similar output. Two points on which the French design differs from the Calder Hall station: it uses horizontal instead of vertical channels, and it is designed to permit charg-

SWEDISH CONFEREES Lars Carlbom of Swedish Atomic Energy Company, left, and Torsten Magnusson of government's Atomic Energy Delegation, are interviewed by NUCLEONICS reporter

ITALIAN DELEGATION arrives for morning session. In background: Westminster Abbey

Looks at Calder Hall

ing and discharging during operation. But to the French the main importance of the symposium was that it was on a design so similar to theirs.

Sweden

Sweden is interested in relatively small water-moderated and water-cooled plants for heating purposes. Therefore the Calder Hall design *in toto* was of no interest to them. However they were quite interested in questions relating to reactor safety and to the British approach to shielding. They hoped to find useful ideas in the British answers to these problems. According to Dr. Torsten Magnusson of the Swedish Delegation, within 20 years Sweden will have to develop a strong nuclear power program to meet the gap in its energy needs. The first Swedish reactor for heating, with an output of 100 Mw (heat), is planned for operation in 1960. By 1962 Sweden hopes to have in operation a dual-function reactor that will have an output of 14 Mw electrical and 75 Mw heat (*see p. R10*).

Another Swedish interest was expressed by P. H. Margen of the Swedish Atomic Energy Company, who was looking for details on graphite manufacture and fabrication.

Italy

A large delegation from both government and industry was present. It was on a shopping tour, for Italy anticipates a need for several large power reactors of the Calder-Hall type. One member of the delegation said the Italians were coming away from the symposium with the impression that the British type was much more suited to the needs of European countries, particularly owing to its use of natural fuel, than anything the U. S. had to offer. He said the experience the British have gained in actually operating this type would also be invaluable to any country purchasing one. The Italians have bought a 5-Mw heavy-water research reactor from the U. S. which they hope to have operating in one year. They plan to buy their power reactors abroad as well. The Italians also were quite interested in the fact that the British had pushed this type of reactor while the U. S. has passed it up completely.

One Italian commented that Calder Hall itself is already an obsolete station and complained that the British companies were unable to give full information to them on the more advanced sets because details are being withheld until after the announcement of awards on the bids for the Central Electricity Authority stations.

Netherlands

Representatives of the Dutch government also mentioned that while they were able to talk with the AEA, they were not permitted to discuss the new designs with the companies. The Dutch definitely are in the market for a power station of about 125 Mw. They are considering two types: Calder and the PWR. They would prefer to stay with natural uranium.

Switzerland

The Swiss sent Jacques Lalive Dépinay, representing Brown, Boveri & Co., one of a small group of foreign delegates to visit Calder Hall after the symposium. He was greatly impressed by the similarity that fabrication of the Calder-Hall type bears to conventional steam plants, but had formulated no preference as yet between graphite-moderated and pressurized water reactors.

Denmark

Research director P. C. Jacobsen of the Danish Atomic Energy Commission, though impressed by characteristics of graphite-moderated gas-cooled reactors, said no firm plans had been formulated. The commission has no design or manufacturing powers but will act in an advisory capacity to industry. But, he thought, because of the shortage of suitable coal in Denmark it was likely that a decision would eventually be made in favor of the Calder Hall type of around 100 Mw.

NUCLEONICS Asks U. S. Conferees:

Some of the Americans who arrived for the Calder Hall symposium as skeptics departed skeptics. But to NUCLEONICS, one of the surprising things about the symposium was the amount of American enthusiasm generated. In general, the American group was convinced that the British have something that will offer stiff competition in the export market. The Americans also were impressed by the completeness of the information provided. The British told all, in every field except economics.

On many occasions—before, during, and after the symposium—NUCLEONICS reporters discussed Calder Hall and the problems of nuclear power with the American delegates. The conversations were informal, frank, and peppery. What follows is a composite of these various "bull sessions." It is not presented as a complete verbatim rendition, but it is a faithful reproduction of both the language and spirit of the information exchanged.

Q. How complete a picture did you get of Calder?

• About as complete as we could get without digging through the place. They gave us everything but the specs and drawings.

• I'm going to report to my boss that the Britishers have done a good job. They know it and they want the world to know it. That was the purpose of this meeting as I see it. I would say that the completeness of information presented was good. They told me more than I could use.

• I don't agree. If you go home and analyze the information very carefully you've going to find you have an incomplete system of information. You will not be able to compute all the way around the circle. This is a hunch I have.

Q. Did you learn anything that you didn't know before, or general solutions you didn't know could be applied?

I doubt it. On the other hand, we heard this whole thing rehearsed a little over a year ago at Geneva. The difference between Geneva and today is quite marked.

Q. Did you learn anything you'd really call new?

I did, yes . . . but it was in the nature of detail.

Q. In the foreign market, do you think we have anything today to compete with the industrial version of Calder Hall in small-size plants?

In small size, no. There's nothing in the U. S.

Q. What about our PWR?

No, that's not small.

Q. Are you saying actually that we don't have any small plants of less than 30 electrical Mw to offer for foreign consumption today?

Well, I don't think we have any reactor plant that's designed to work on natural uranium. However, I think you're asking a question that can't be answered explicitly or accurately. It depends on the economics of these systems. Now I've made a rough estimate and I compute that the Calder Hall type plant, as it is without any improvements, costs about 19–20 mills/kwh for Britain. And I'm computing according to reasonable methods. I'm using 13% on capital, 8% on fuel inventory. I'm doing it the standard American way.

Q. But they don't do it the standard way, do they?

The point is this: you can ask various reactor manufacturers to talk about making a 30–40-Mw job. What kind of investments have we seen published for net costs? I think for pressurized water reactors, instead of 20 mills/kwh you might be talking 15, maybe 20. You see, you just don't have enough accuracy in these estimates to answer the question of whether we can compete.

Q. Haven't fixed prices been quoted for foreign use for boiling-water reactors in just about the range you're talking about, and just about the power rating?

• Yes, but the British haven't actually built the plant for which those figures are cited, any more than we have. We have a reactor that will compete with those costs if we built it in Britain right now. That's the boiling-water reactor in the 30-Mw region. It goes critical this month. So if we wanted to, we could sell in the export market just as well as they could sell the Calder Hall type.

• I'm surprised that you even assume that the steam reactor can get down to 30 Mw and really compete.

Q. We've talked about small plants but I don't think we actually discussed the ability of the U. S. to compete with Calder Hall in the large-size plants of 100–200 Mw. Can the U. S. compete there?

We can on our capital cost structure. We cannot on the British capital cost structure.

Q. You mean if we use ours and they use theirs?

I mean even if we use our reactor and their reactor in their country, we can't compete. One of the things about the economics of the Calder Hall type reactors is that not only is the reactor geared to Britain in that it uses natural uranium, graphite and CO_2, but the economics is also geared to Britain. As far as I'm concerned, looking at it from the U. S., I think the Calder Hall reactor is excellent for the British. My only resentment about the Calder Hall reactor is when some people become convinced on short acquaintance that this is fine for the U. S. The second thing I resent is that they carry this over and think it's also fine for places like Japan where they haven't analyzed the situation and conceived what the situation is. So my feeling is that Calder Hall is fine for the British. They can do all the patting themselves on the back they did for the past two days and I'm all for it. What I don't want to see is the U. S. or foreign countries sucked in on this thing without thorough analysis of it within their own economies.

• Consider Japan: it has the cheapest labor of any major power, and yet analysis indicates that PWR and Calder Hall in Japan are practically the same cost. So you can't go solely on the basis of the local labor cost. It's the local cost of capital and all kinds of complicated factors that come into this. The latest conventional plants in Japan cost just as much there as they do in the U. S. As far as we can tell, the cost of importing equipment either from the U. S. or Britain to Japan, or using Japanese-made equipment, is almost the same—so it doesn't matter which way you go. In fact, importing may be a little more expensive but essential, because Japan can't make all of this equipment right now. They admit that they can't, until possibly 1965. That's one of the things that worries them—that the foreign exchange drain for atomic energy in Japan is going to be tough for the next 10 years. After that they think they can make most of the equipment themselves, and therefore they'll do better by using atomic power than by having to import a lot of oil.

Q. Would Japan have to import less for a Calder system on their present standard of technology?

I'll give odds they could fabricate a Calder Hall pressure vessel a great deal easier than a PWR, although they'd probably have to import British engineers to tell them how to do it.

What Does Calder Mean to You?

Q. Don't you think there are noneconomic factors that must be considered in this whole situation?

• Well, I would like to try to draw an analogy between the reactor development business and the nationalistic aspects of natural uranium and, let's say, the automobile business. Each small country in Europe feels it has to develop its own automobiles. As a result they pay more for less efficiency and so forth, because they will not buy from the countries that can produce cheaply and efficiently. I think some of this nationalistic and political feeling may be arising in the case of enriched uranium. Countries are actually going to penalize themselves in efficiency and higher capital costs just because they have to have a bigger reactor to go with natural uranium rather than have faith that the U. S. will supply enriched uranium.

• For my part, I would add: if the U. S. is going to make any contribution in the foreign reactor field, it had better not shut its eyes to this natural-uranium approach. You have only two fuels: low-enrichment uranium and thorium. To make the thorium cycle go is expensive. You need high-performance reactors of high specific power because you're using a very expensive fuel. With natural uranium you can afford a much lower specific power.

• I'd like to argue on the other side, although in the case of many countries I agree with you on appeal; but I think that the appeal is based on a false understanding of the situation. The thing that most of them are ignoring is that no matter what they start with, they're going to have to use plutonium, and if they're going to use plutonium, they're going to have to build enriched-fuel reactors. It seems to me that the U. S. Atoms for Peace plan is offering a temporary way to get into the business with enriched uranium. Subsequently, foreign countries can substitute their own locally-made plutonium for enriched uranium and jump the natural-uranium step.

Q. Any other points?

Yes. I have some other information that you may all know but I'll throw it in for what it's worth. I was talking to one of our Italian friends, and the British have made a proposition. They will supply Calder-Hall fuel elements canned, put them in the reactor for £26 ($73), and buy them back at a guaranteed price of £11 pounds/kg ($31). So it's £26/kg to get them, £11 back, and although they don't guarantee 3,000-Mw-days/ton they expect to get it. So if you use their 3,000 Mw-days/ton you end up with a fuel cost of 2.3 mills/kwh. And that is top competition.

Q. In terms of detail, what striking features, if any, did you find in plant design?

There's no doubt but that the use of magnesium is new. We knew about magnesium alloy but I still wonder how they can get away with the magnesium alloy, however pure, at 400° C (752° F) when at 550° C (1,022° F) magnesium begins to reduce CO_2 like nobody's business. You would expect an attack at a hot spot on the jacketing at 550° C and I would think that a range of 150 degrees for a local spot could occur very easily. But you noticed they were running 50° F under design output temperature.

Q. On heat transfer specifically—of what interest is that in the U. S. program?

• A lot higher than we usually get, and it's much higher still in the CEA sets.

• It's all very fine if you're talking about a poor gas like CO_2 and good metal like magnesium. But if you're talking about a poor heat-transfer material like stainless steel and a good gas like helium, for instance, you're wasting your time.

Q. Does the advantage of the so-called transverse fin result from the increased surface that you can get?

Yes, you just get more surface. You probably don't use it as efficiently as longitudinal fins but you get more surface [*see p. 816*].

Q. Do you have any ideas about the excess reactivity they could be getting in this reactor with all this magnesium and with all the gaps they could have, and with natural uranium, and with what we know as a good grade of graphite?

• I doubt if they have a k_∞ of more than about 1.06, 1.05—it's been published. They have about 2% xenon.

Q. Any comments on graphite as a moderator?

Yes. The graphite delivered was better than expected, and better than promised. It gave them some excess k—probably 0.005; better than they expected.

Q. What about the supply of graphite?

So far as I know, the U. K. has been supplied with all the graphite they needed when they needed it. I don't believe they have been delayed a day, and this should be no problem in the future.

Q. Do you believe the economics that you've heard presented?

The economics of Calder and Calder-type plants is quite good from hearsay. I don't know. There are enough hidden subsidies that I just don't know about, and I don't believe there is anybody who can tell me.

Q. Do you think it makes sense for the U. S. to build a Calder-type reactor?

No. The Calder-Hall type is no good unless you've got magnesium. You'd have to repeat the whole English technology, redevelop the whole thing, develop uranium the way they do, develop fuel elements they way they do, develop magnesium the way they do. And in the end you'd have a plant which could not be competitive in the U. S. You'd be spending an awful lot of money and development time and energy on a plant that would teach you to do nothing but build more of the same and it wouldn't be economical. The fixed charges they use are 8.02%. Now any of us who are in the reactor business here know the standard number is 13% in the U. S.

Q. If the British build a pile for a foreign country in that foreign country, they'll get better economics than we will by taking our high-priced labor and building it in their foreign country—isn't that so?

• If you sell a reactor to a government, then the economics will be something like Great Britain's. If you sell it to a private industry, it will be something like America's. This kind of thing will influence U. S. ability to compete in the immediate future.

• I think the British have a foreseeable market in which they can develop this product to a higher degree of perfection. None of our reactors have this possibility and to me this is worth a lot in cost reduction. It makes up for a great deal. The British can economically use these reactors now. They're going to build a long, large series of them. Even if they don't go out for 25 years, there'll be enough of them to give the British a lot of experience on how to do them better and the thing will be highly perfected before it dies out. One Britisher said in Geneva last year, "Maybe this is a model T, but we're going to have kilowatts on the grid while you Americans are deciding what's the best kind of reactor to build."

Economics and Future Design

THE CALDER HALL economic data should not be used as a basis for a long-range evaluation of the gas-cooled type of reactor any more than the first Shippingport reactor cost data should be used as a long-range criterion for pressurized-water reactors. The Calder Hall plant is a sort of reactor experiment and was designed as a plutonium producer first and a power producer second.

Relative values of the operating cost of the Calder Hall reactor are of interest, however, because they can give some sort of a basis for our long-range expectations.

Table 1 shows the cost per kilowatt hour of the Calder Hall plant operated at 80% load factor with fuel irradiated to 3,000 Mwd/ton and a fuel loading costing $56,000 (£20,000) per ton.

An accurate analysis of the Calder Hall type of reactor will be possible as soon as the contents of the four bids to the U. K. AEA are made public. However, it is possible to make certain calculations of fuel costs based on available information. With the prices of $56,000 per ton of natural uranium in the form of fuel elements and a resale value of $16,800 per ton after 3,000 Mwd/ton irradiation, the cost comes to:

Operating cost	2.2 mills/kwh
Inventory charge at 6% (4% plus holdup for cooling and shipping)	
Present heat rate	1.5 mills/kwh
Double present heat rate	0.75 mills/kwh

Thus it appears that a total fuel cost of 3 mills/kwh will be achievable with Calder Hall reactors if, as is probable, doubling of the heat rate is possible.

The plant of the Calder Hall variety must of necessity be operated as a base-load plant since the installed cost and consequently the fixed charges will be high with a rather lower operating cost. The corollary is that minimum interruption for refueling is required, indicating that future Calder Hall designs should be capable of being refueled without disturbing system pressure.

The basis for the fixed charges in the Calder Hall reactor is very different from the basis used in the U. S. for either conventional or atomic power generation. In common U. S. practice, 14% for conventional plant and 15% for atomic plant is used to cover debt service, amortization, and depreciation.

The charges used for the Calder Hall reactor are 4% for the interest and 20-yr depreciation for an average total of 8.02%. Thus the already high capital charges of the Calder Hall reactor would be nearly doubled if the plant were to be built in the U. S. or in a country with an equivalent economic structure.

TABLE 1—Cost of Calder Hall Electrical Output

	mills/kwh	*(pence/kwh)*	%
Capital charge	6.5	(0.56)	53
Fuel inventory charge	1.2	(0.10)	9
Fuel consumption charge	4.1	(0.35)	33
Operation and maintenance	0.6	(0.05)	5
Total	12.4	(1.06)	100

Plutonium Production

The Calder Hall reactor will generate a substantial amount of plutonium. This plutonium will have, of course, a value when used in weapons but advanced planning based on plutonium recycling has been carried out.

The plutonium formed could be used directly in place of U^{235} in small enriched reactors in which the problems of fuel-element fabrication could be overcome, and it could be used also to provide additional reactivity in other plants.

In addition, the possibility of long-range multiple recycling of plutonium has been considered. However, this procedure has disadvantages because as plutonium burns, Pu^{240} and Pu^{242}, which are nonfissionable, are produced in large quantities. Their equilibrium concentration is dependent only upon their neutron capture rate. Their adverse effect is brought out clearly in Table 2.

Fuel burnup. The importance of long reactor burnup is shown in Fig. 1. It appears that 2,000–3,000 Mwd/ton is essential and that there is relatively little interest in going beyond 4,000–5,000 Mwd/ton.

Higher-Pressure Operation

The performance of the Calder Hall type of reactor is limited by the maximum estimated pressure that can be

TABLE 2—No. of Pu Atoms to Replace One U^{235} Atom without Altering Reactivity

For pure Pu^{239} fuel	0.44
For 3,000 Mwd/ton Pu from natural-U reactor	0.75
For equilibrium plutonium	2.38
For equilibrium plutonium without Pu^{242}	0.99

TABLE 3—Increased Efficiency with High Temperature

	Heat output (Mw)	*Electrical output (Mw)*	*Fuel rating (Mw/ton)*	*Efficiency, electrical/heat (%)*
Case A: larger Calder design	400	100	2	25
Case B: High-temp. reactor				
Flattened neutron flux	1,400	433	5.8	31
Unflattened flux	1,100	340	4.5	31

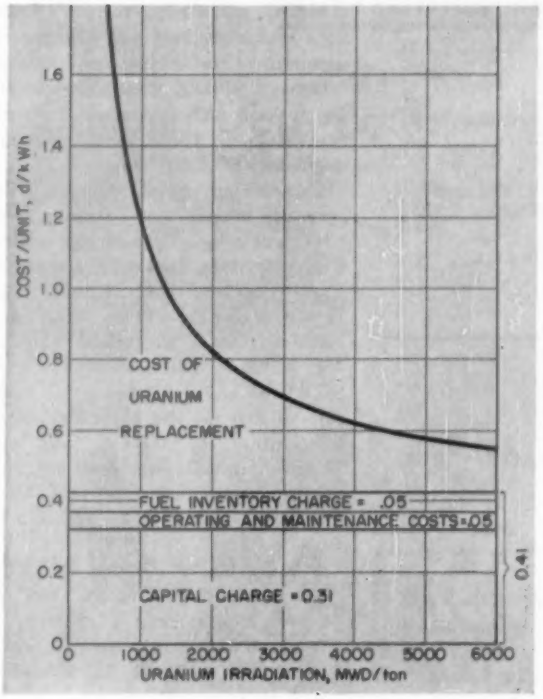


FIG. 1. Cost of electrical output of power station (costing $350/net kw, operating at 80% load factor and 25% efficiency, uranium costs $56,000/ton, assuming fuel elements have no residual value)

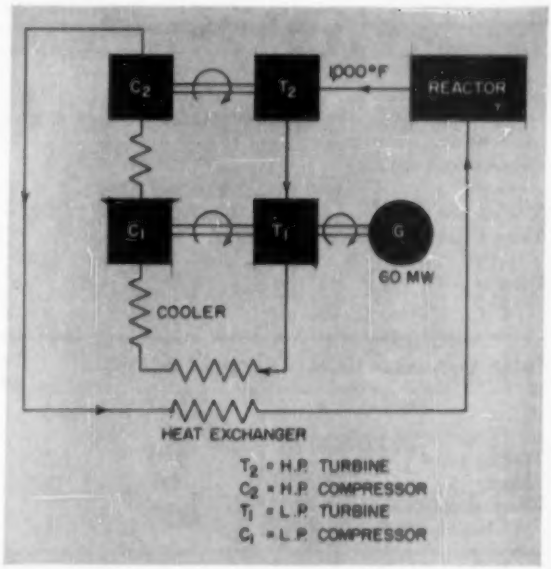


FIG. 3. Escher-Wyss type of gas-turbine cycle. Reactor feeds high- and low-pressure turbines; latter drives alternator

accommodated as well as by the maximum estimated temperature. Since the core is extremely large (~30 ft) it becomes necessary to fabricate the reactor on the site.

The present Calder Hall reactor vessel is limited to 2-in.-thick steel plate. In the event that greater thicknesses of steel plate are available, the heat output of a given reactor can be increased substantially for a given pumping power. Since the total capital cost of the plant will increase much more slowly than the reactor thermal power, the final cost per kilowatt would be expected to drop considerably from that of the present Calder Hall reactor.

Since operation at a higher pressure level would not in any way change the basic metallurgy and physics of the Calder Hall reactor, the possible change to higher plate thickness would only depend upon the ability of the constructor to fabricate pressure vessels of greater thickness.

Preliminary reports indicate that it is possible to fabricate spherical pressure vessels of acceptable size and 3-in. thickness. This should provide a substantial power increase.

Higher Temperatures

As a long-range development the use of high-temperature gas-cooled reactors is currently being considered. These reactors would require a completely different basic technology from the Calder Hall type.

If high-temperature reactor operation were possible, e.g., with other fuel-cladding materials, a substantial increase in efficiency and decrease in capital cost would result. This increased efficiency is shown in Table 3.

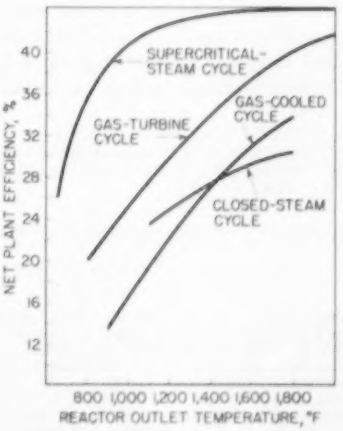


FIG. 2. Higher thermal efficiency obtained with supercritical-steam and gas-turbine cycles compared to closed steam and helium cycles

The case B reactor is designed for 1,100° F (600° C) operation, which was selected without reference to a particular material. This temperature shift would require complete reinvestigation of all the basic metallurgical problems in the Calder Hall reactor. The reaction of CO_2 with every material in the reactor could be expected to be speeded up. It is unlikely that these improvements could be made in the near future.

Effect of fuel element design. Table 4 shows that it is not possible to raise the maximum temperature of aluminum- or magnesium-clad elements much above the present value of 400° C because of their low melting points. Thus the magnesium technology has about reached its limit and to get substantially higher temperatures, other materials must be considered. However, the other metals listed have substantially worse thermal conductivity and, in two cases at least, have a relatively large neutron-capture cross section.

The low thermal conductivity means that the fin efficiency of extended surfaces would become so small that fins would not be effective. The high neutron cross section means that a depar-

TABLE 4—Possible Uranium Cladding Materials

	Aluminum	*Magnesium*	*Beryllium*	*Niobium*	*Zirconium*	*Stainless steel (18/8/1)*
Neutron cross-section (cm^{-1})	0.0118	0.0023	0.00011	0.061	0.0076	0.227
Melting point (°F)	1,220	1,202	2,343	4,379	3,362	2,732
Thermal conductivity (C.H.U./hr/ft/°C)*	130	90	70	36.4	14.4	9.2
Density at 68° F	2.7	1.74	1.85	8.57	6.5	7.9

*C.H.U. is centigrade heat unit.

TABLE 5—Possible Uranium Ceramics for Fuel

	U	*UC*	UO_2	UC_2
Melting point	2,070	1,082	4,532	4,100
Density	19	13.5	11	11.28
Thermal conductivity at 122° F (C.H.U./hr/ft/°C)	3.75	4.6	0.29	0.47

ture from the basic concept of natural uranium fuel would be necessary.

Ceramic fuel elements. The possibility of ceramic fuel has been considered. Table 5 gives the properties of some of the common ceramics.

The use of ceramic elements at gas-outlet temperatures of around 1,500° F (800° C) presents a brand new materials problem. The thermal and irradiation stability of the graphite and the ceramic presents a larger research problem. It would be highly desirable to prevent the spread of fission products into the primary coolant loop. The over-all efficiency of such plants could, however, be comparable to the highest steam plant efficiency obtained today.

Gases other than CO_2. Other gases have been considered as an alternative to CO_2. Helium of course is preferable on chemical and high-pressure grounds, but would not be available in the quantities necessary. Hydrogen has excellent heat-transfer properties but essentially unknown chemical properties, and, of course, in the event of hydrogen leakage, a serious explosion hazard would exist.

If a gas with better heat-transfer properties is used, however, the value of the fins will be seriously reduced and then a basic change in fuel-element design would be indicated. The only way to satisfactorily compare the performance of different gases is to prepare a detailed design.

Steam cycles. It was pointed out by W. R. Wootton of Babcock & Wilcox Ltd. that the application of supercritical steam cycles to the gas-cooled reactor might give extremely high thermal efficiency at temperatures lower than those required for reasonable gas-turbine operation. Figure 2 compares closed steam and helium cycles* with a supercritical steam cycle and a somewhat more efficient gas-turbine cycle. The steam-cycle data is perhaps a little optimistic and the gas-turbine cycle a little pessimistic, but it is clear that a supercritical water cycle may offer an extremely efficient means of generating power from intermediate-temperature reactors. This temperature range might be 900°–1,100° F.

Gas-turbine cycles. Operation at very high temperatures naturally leads to consideration of gas-turbine cycles. The cycle of the Escher-Wyss type has been considered by Stenning and Howieson of Chalk River. The schematic diagram of the cycle is shown in Fig. 3. Both CO_2 and helium were considered and a maximum gas pressure of 300 psi and a maximum gas temperature of 1,000° F (538° C). These are probably the most unfavorable conditions that could be selected for a cycle that could be expected to work.

The machinery required would be large and costly. Even at 1,000° F, however, the calculated efficiency is 29% and if the temperature were raised to 1,250° F (677° C), the efficiency would be 38%. To achieve competitive capital cost with steam, the pressure would have to be considerably higher than 300 psi. However, it seems likely that pressures up to 1,000 psi could be feasible with this sort of system and the rotating machinery could be made quite small and compact.

* "Reactor Handbook: Engineering," p. 377 (U. S. Atomic Energy Commission and McGraw-Hill Publishing Co., Inc., New York, 1955)

Summary

The Calder Hall reactor with its solid-rod fuel element clad in magnesium or aluminum is probably near the end of its ultimate development so far as temperature is concerned. Increases in system pressure will of course result in increases and improvements in plant economics. A new technology of materials would be required for the next step of large increase in temperature, along with the application of closed-cycle gas turbines as an alternative to steam.

WHERE CREDIT IS DUE

The technical description of the Calder Hall Nuclear Power Station given here was derived in large measure from papers presented at the Calder Works Symposium, November 22 and 23. The complete proceedings will be published in the April and July 1957 issues of the *Journal of the British Nuclear Energy Conference*.

The titles of the papers and their authors follow: Sir Christopher Hinton, The place of the Calder Hall type of reactor in nuclear power generation; R. V. Moore, B. L. Goodlet, The 1951–53 Harwell design study; R. V. Moore, The design and construction of the plant; P. Fortescue, W. B. Hall, Heat-transfer experiments on the fuel elements; P. W. Mummery, Experimental physics; C. C. Horton, W. Bonsall, Shield design; G. Packman, B. Cutts, Basic design of reactor; R. A. U. Huddle, L. M. Wyatt, Early metallurgical problems; L. Grainger, A. B. Mc Intosh, Metallurgical developments; G. Brown, M. J. Noone, R. F. Bishop, Design and construction of reactor vessel; K. H. Dent, G. W. Grossmith, Uranium fuel handling; A. T. Bowden, G. H. Martin, Design of important plant items; W. R. Wootton, Steam-cycle analysis; H. Morris, W. R. Wootton, Design and construction of heat exchangers; S. A. Ghalib, J. H. Bowen, Equipment for control of the reactor; E. Long, J. M. Laithwaite, K. W. Cunningham, Detection of faulty fuel elements; R. J. Cox, K. R. Sandiford, Reactor control and instrumentation; E. Anderson, J. H. Bowen, System control and instrumentation; R. V. Moore, Future developments of gas-cooled reactors.

Gamma Dose Rates in Cylindrical Sources

By DONALD R. SMITH and MARVIN C. ATKINS
Air Force Institute of Technology, Dayton, Ohio — *Wright Air Development Center, Dayton, Ohio*

WHAT GAMMA-RAY exposure dose rate* will you find at the center of a given cylindrical Co^{60} source? How should you design such a source for a required flux in a given volume? Figures 1 and 2 are designed to answer such questions. By appropriate conversion they can be used for other gamma emitters. The computations are an extension of earlier work (*1*, *2*).

Figure 1 is a plot showing the gamma dose rate to be expected at the centers of cylindrical sources of various sizes and activities. Self-absorption and backscatter are neglected. To use the graph for other gamma-emitters one must multiply the ordinates by $M/14.7$, where M is the exposure dose rate in r/hr 1 ft from a 1-c point source of the other isotope.

The following useful rules will be found to follow from this method of source design:

1. For a specified total activity, an increase in the flux by a factor of 10 will decrease the useful volume by a factor of 31.6 ($1{,}000^{2/3}$) if the same relationship between the average radius and height is maintained.

2. For a specified central dose rate an increase in the total activity by a factor of 10 will increase the useful internal volume by a factor of 31.6 if the radius-height ratio is maintained.

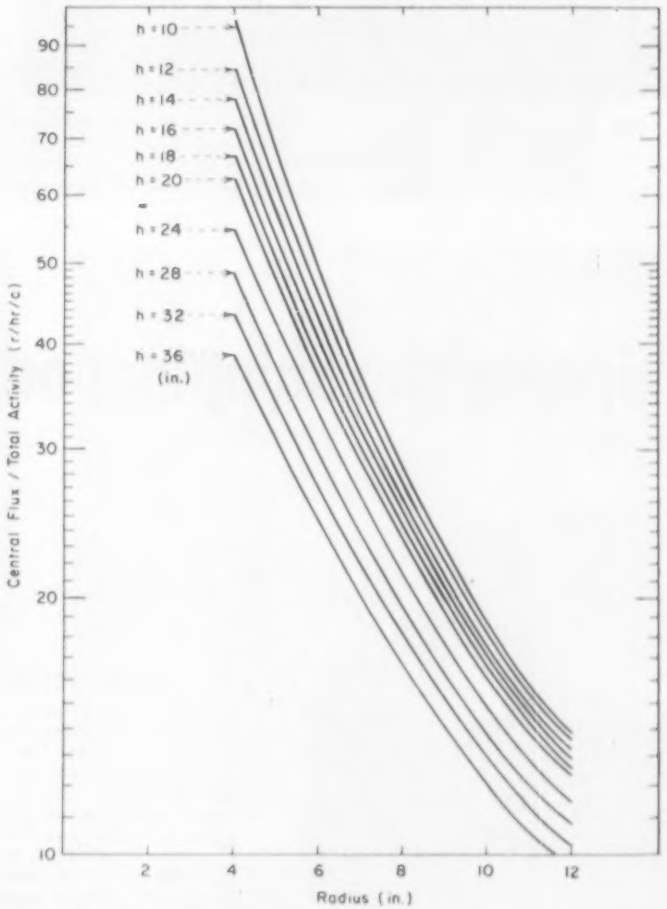


FIG. 1. Exposure dose rate at center of cylindrical cobalt source is a function of activity, height, and radius. Ordinate gives flux per total activity

* The International Committee on Radiation Units has recommended introduction of the terms "exposure dose" (measured in roentgens) and "absorbed dose" (measured in rads) to reduce the confusion between the radiation field and the energy absorbed in any exposure.

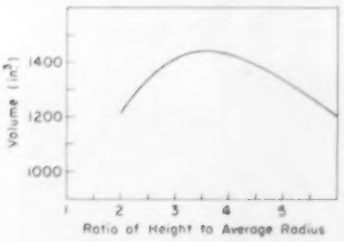


FIG. 2. Volume of 10,000-c cobalt source with central flux of 5×10^5 r/hr as a function of ratio of height to average radius

Example. "Select dimensions to give maximum interior volume of a 10,000-c cobalt source if the central flux is to be 5×10^5 r/hr." Since $5 \times 10^5/10{,}000 = 50$, we follow the 50-r/hr/c line across the graph to find appropriate combinations of dimensions. Usable values are $h = 24$, $b = 4.4$, etc. In Fig. 2 we plot the volume as a function of h/b. The maximal volume is found to be 1,440 in.^{3} for $h/b = 3.6$. The closest integral values that correspond to this volume and ratio are $h = 18$ and $b = 5$ in. From Fig. 1 the central dose rate in a 10,000-c source of these dimensions would be 5.02×10^6 r/hr.

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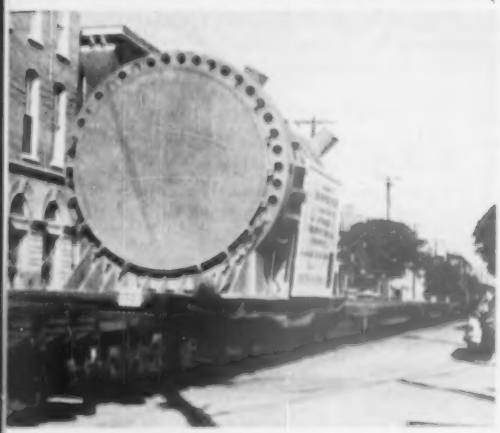
2. J. G. Lewis, J. V. Nehemias, D. E. Harmer, J. J. Martin. NUCLEONICS **12**, No. 1, 40 (1954)

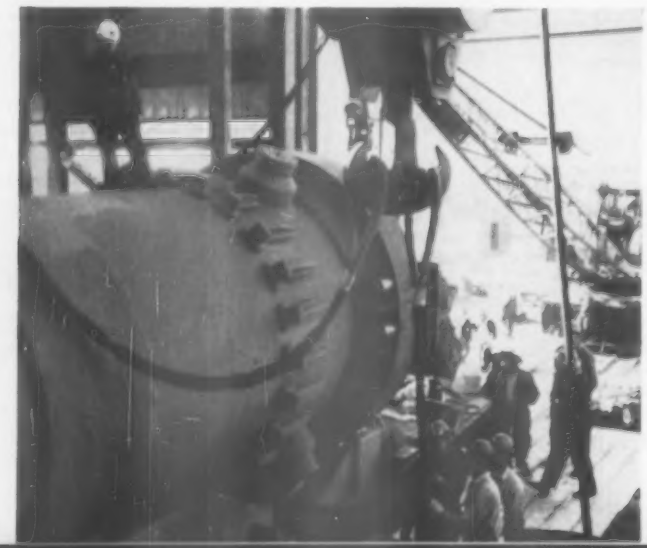
LID STAYS . . . The 85-ton removable reactor-vessel closure being fabricated at Combustion Engineering's Chattanooga shops. It will have 46 openings in dome for fuel-handling equipment, instrument leads, control rods. Delivery is set for January. (Right) 42 such bolts will fasten head to vessel during operation. Each 80½-in.-high 6-in.-dia bolt weighs 700 lb with its nuts

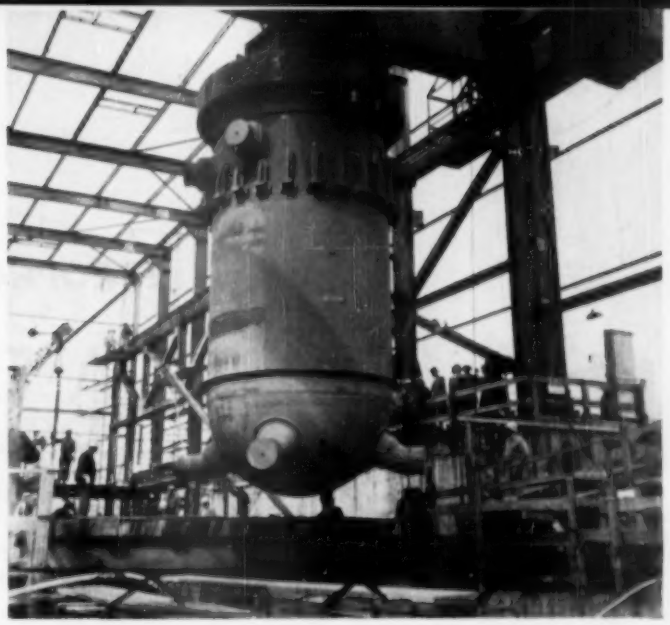
Shipping the Shippingport Reactor Vessel



. . . WHILE VESSEL GOES . . .

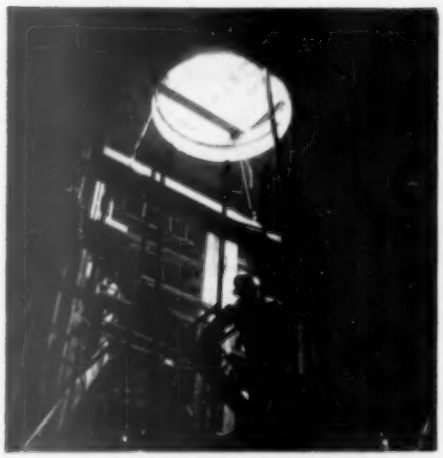
Special 80-ton, 24-wheel 58-ft-long flatcar had to be routed over 1,075 miles of wide-clearance track to negotiate 365 crow-flight miles from Chattanooga to Shippingport, 33 miles west of Pittsburgh. Trip took 10 days, in daylight only, at 16 mph maximum. (Top left) Reactor vessel on right-of-way between Halifax and Millersburg, Pa., on banks of Susquehanna river; (lower left) passage through downtown Shippensburg, Pa., west of Harrisburg. (Below)* Unloading vessel at Shippingport destination, flatcar is brought into unfinished nuclear power plant



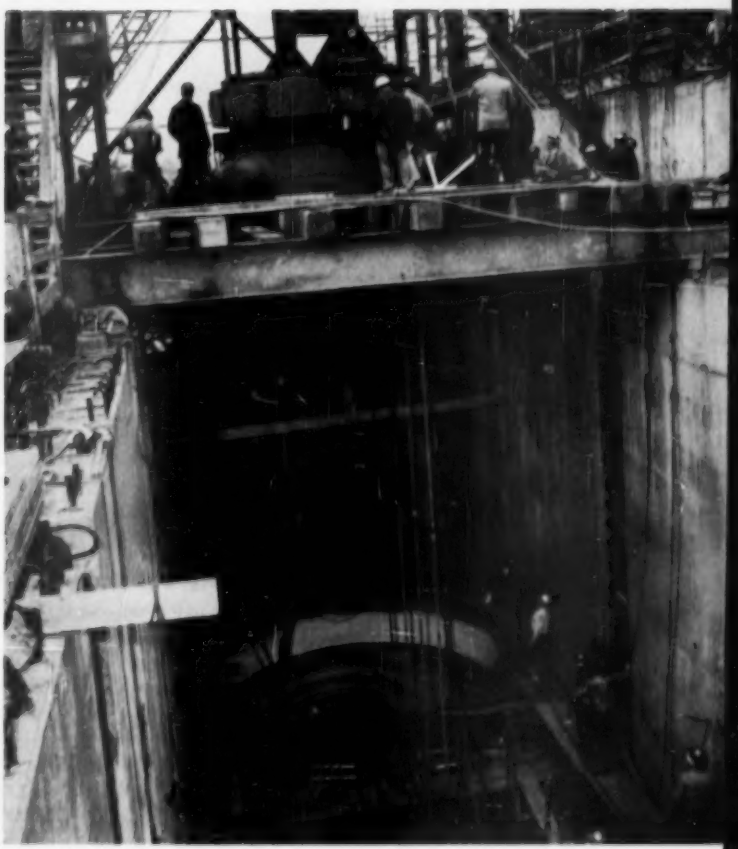


... TO ITS INSTALLATION

Reactor vessel, lifted from flatcar, is poised above steel vapor-containment tank prepared for it 65 ft underground. Vessel weighs 150 tons, is 32.7 ft high, 9 ft i.d., with walls 8½ in. thick bearing a ¼-in. stainless steel lining*



View from inside underground vapor-container into which reactor vessel is about to be lowered through access opening at top*



Vessel is lowered into place, approaches vapor-container access opening. Made from heaviest steel plate ever rolled by Lukens Steel Co. at Coatsville, Pa., vessel took two years to build, required pioneering fabrication methods, cost well over $2-million. It will hold 100-ton core assembly and thermal shield, water circulating at 2,000 lb psi*

Vessel enters vapor container. Dravo Corp. is installation contractor for Westinghouse, who is designing and building the plant for Duquesne Light Co. and the AEC*

* Photos by Grant Compton of Business Week, a McGraw-Hill publication.

FIG. 1. Zirconium scrap aflre in outdoor storage bins in May 1955, after heavy rain. Following initial blaze, flare-ups occurred in several non-adjoining bins, as well as spreading from bin to bin; 159,000 lb of Zr scrap were involved
FIG. 2. General view of zirconium-scrap storage facility. It had been thought separating walls would be sufficient to prevent spread of fire in case one broke out; this turned out not to be case

PYROPHORICITY—

A Technical

An AEC official tells what we know—and what we don't know—about a major problem in the nuclear materials field, now the object of three studies

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U. S. Atomic Energy Commission
Washington, D. C.

PYROPHORICITY* is, unfortunately, a property of several of the metals most widely used in atomic energy programs. Plutonium, uranium, thorium, zirconium, and hafnium are afflicted, as are magnesium, calcium, sodium, and potassium.

That this is no mere academic consideration is attested by the fact that half of AEC's 1955 monetary loss from property-damage incidents peculiar to nuclear activities stemmed from decontamination activities following spontaneous fires in radioactive metals.

Yet our understanding of pyrophoricity is very meager, quite inadequate to cope with the broad range of behavior exhibited by pyrophoric metals. Some of the phenomena observed and some possible mechanisms are discussed here; research now underway (see boxes on p. 29 and 31) should fill in the picture considerably.

* [illegible] pyr·o·phor'ic (-fôr'ik), *adj.* [Gr. pyrophoros fire-bearing, fr. *pyr* fire + *phoreus* to bear.] Light-producing; igniting spontaneously; of or pertaining to pyrophorus.
pyrophoric alloy. *Metal.* An alloy, as ferrocerium, having the property of emitting sparks when scratched or struck with steel. Such alloys are used for automatic gas and cigar lighters. See PYROPHORIC.
pyrophoric (pī-rō-fŏr'ik), *adj.* Pyrophoric.
pyrophorus (pī-rŏf'ŏ-rŭs), *n.*; *pl.* -ri (-rī). [NL.] 1. [illegible]

Nature of Pyrophoricity

Although pyrophoric metal fires are infrequent, the cumulative experience in handling large quantities of these metals includes thousands of incidents. The vast bulk of these were minor spontaneous fires involving no property damage. However, a number are unusual incidents, the causes of which are difficult to explain rationally; a few involved fatal injuries and major property damage (*1, 2*).

The range of contrasts covered by such vagaries is indeed impressive. For example, massive (i.e. solid chunk rather than powdered) uranium will not normally ignite even when heated to its melting point—yet a case is known where a yeast-cake-size piece of massive U ignited spontaneously while resting on dry ice, and in another case a U specimen at room temperature spontaneously exploded. Spontaneous U fires have occurred under vacuum, under water, and under argon atmospheres. Spontaneous ignition and continued combustion of massive Pu, U, and Th specimens have occurred in air at room temperature.

Liquid-Combustion Analogy

Unlike flammable liquids, metals do not ignite at consistent temperatures when heated in air. Metallic U, for example, can ignite spontaneously in air at room temperature when in the form of fine powders, but massive metal will not normally ignite even when heated to its melting point.

At the risk of oversimplification, a further comparison with flammable liquid combustion is helpful in obtaining a better understanding of observed vagaries in metal fire and explosion properties.

Flammable vapor-air mixtures burn only when the concentration of vapor is

Mystery Under Vigorous Attack

between the lower and upper explosive limits. It is important to note that actual combustion involves an air–flammable-vapor reaction and *not* an air–flammable-liquid reaction. Experiments indicate that free burning of metals in air takes place at temperatures well above the metal melting point, at which temperatures the metal vapor pressure is well within a range comparable with that of flammable liquids undergoing combustion.

When a small amount of flammable liquid is burned, the heat of combustion raises the temperature of the liquid to its boiling point where it remains constant until all of the liquid has vaporized. A very recent experiment involving free-burning tests of small magnesium specimens indicated that combustion took place while the Mg temperature was very close to the boiling point. Such data again suggest a close analogy between the mechanisms respectively involved in combustion of flammable liquid and flammable metals. (Recent high-speed movies of an Mg wire burning in oxygen showed that combustion rates along the wire were erratic and that oxidation was accompanied by periodic small localized high-energy explosions, the causes of which are uncertain.)

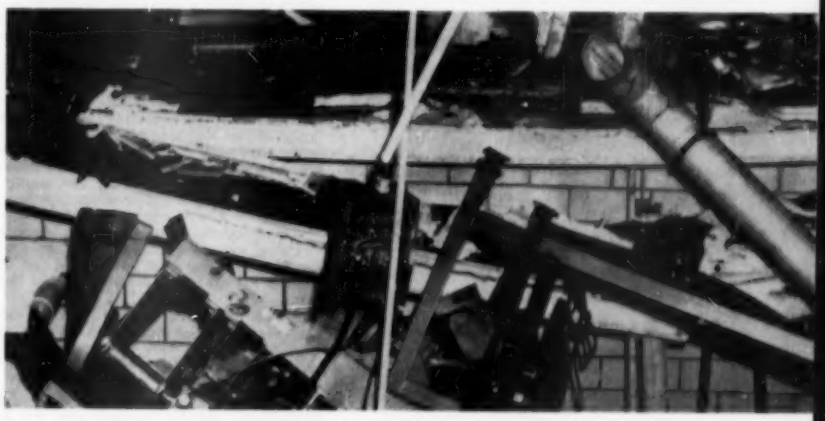

FIG. 3. Close-up of damage in metallurgical laboratory after a thorium explosion in July 1956. Tile is part of wall of ground-floor room; above it is floor of second-story lab room where explosion took place; apparatus seen diagonally in lower left is part of a calciner that had stood on part of floor that dropped: standing next to it had been a drum containing major part of thorium scrap to be burned to oxide. Triggered by initial blast, this material exploded in its wake

When a fire occurs on the surface of a large amount of oil, initially at room temperature and contained in a tank, liquid temperatures at the surface are again at the boiling point while liquid at the base of the tank may remain at the initial temperature. Such fires have been extinguished through use of agitation, permitting replacement of relatively hot liquid oil at the surface with cool oil from subsurface locations.

In the case of massive pyrophoric metals, the surface is similarly rapidly cooled by conduction of heat to subsurface levels at a rate far greater than can take place between quiescent layers of oil. This ability to dissipate heat accounts in large measure for the difficulty in obtaining and sustaining combustion of such specimens without continued external application of heat. In view of the extremely high temperatures required for massive metal combustion, plus the fact that heat-radiation losses take place at a rate proportional to the fourth power of the temperature, the rarity of massive-metal fires is not surprising.

Massive-Metal Combustion

Spontaneous ignition of any massive pyrophoric metal is very rare. How-

AEC's Three-Pronged Attack on Pyrophoricity

Following two recent serious and unusual explosions, involving metallic Zr (*1*) and Th (*2*) (see Incidents listed on p. 30), AEC efforts to study unusual metal fires and explosions were intensified and metal-pyrophoricity research activities expanded.

1. **A fundamental research program covering the mechanics of metal pyrophoricity is being conducted at Argonne National Laboratory.**
2. **A "crash" program aimed at rapidly determining specific methods to ensure safe handling of metallic zirconium was recently initiated by the Bureau of Mines at Pittsburgh (see box on p. 31 for details).**
3. **Very-high-temperature metal-water reactions are the subject of classified research at a third location.**

From these three programs AEC expects to obtain fundamental information permitting increased safety in the manufacture and utilization of such heavy pyrophoric metals as uranium, plutonium, thorium, hafnium, and zirconium. Incidental to the major purposes of this research, it is probable that some fundamental information will also be derived relative to theoretical approaches for attaining oxidation and water-resistant alloys as well as affording a better understanding of the conditions under which high-energy and explosive water-metal reactions may be prevented, controlled, or initiated.

ever, it has occurred in air at room temperatures in the case of Pu, U, and Th with initial metal temperatures ranging from that of dry ice to red heat. Witnesses generally agree that these incidents are accompanied by slow but noticeable flaking off of the metal surface with sporadic emanation of localized sparking.

From these observations it is apparent that combustion of abnormally pyrophoric massive metals includes a "built-in" mechanism for converting a solid metal surface into an extremely fine, brittle, and chemically reactive powder, and that this mechanism is accelerated during auto-oxidation of the powder. Since ignition of massive metal has occurred at quite low temperatures, combustion in air of the surface powder must involve a highly exothermic reaction that more than offsets the heat loss from the metal surface. Thus, a basic mechanism contributing to ultimate burning of massive metal must involve both physical aspects (e.g., stress, brittleness, cracks, voids, etc.) and chemical aspects (initiating and secondary combustion).

Powder Combustion

The large difference in observed pyrophoricity of metal powders and massive metal proceeds from differences in secondary factors influencing combustion efficiency, rather than from any basic difference in the reaction mechanisms involved. To illustrate the magnitude of these secondary "efficiency" factors, identical volumes of solid metal and powder are compared in the table on p. 32.

The table shows that metal powders possess a much greater surface area on which to generate heat, have a much smaller mass of metal in which to dissipate this heat, and have a much smaller percentage of total surface area available for loss of heat by radiation to external surroundings. All of these factors combine to increase the probability of metal combustion.

Effect of mass. Unlike solid metal (in which heat can be internally transferred by the relatively efficient process of direct heat conduction), escape of any heat from within metal powders must largely take place by radiation through multiple insulating layers of air. Thus, accumulation of heat generated within metal powders by slow oxidation becomes increasingly probable with increasing size of the powder

Unusual Metal Fires and Explosions

The following unusual metal fires or explosions that occurred in the U. S. atomic energy program have for the most part been taken from a much more comprehensive list of such incidents (*12, 13*).

It should be noted that such incidents have been relatively infrequent in the large-scale handling of pyrophoric metals over a period of years in the atomic energy program.

In reviewing such incidents, it is of interest to note that increased pyrophoricity can apparently be "built into" a metal at the time of its initial manufacture or may be subsequently acquired as a surface phenomenon.

Zirconium Incidents

¶ Up to May 1955 no serious fires had been encountered during storage of scrap-*Zr* turnings, chips, plates, rods, etc. Such scrap had been stored (pending contemplated future recovery) in segregated open-top bins as shown in Figs. 1 and 2. Several days after a heavy rain, a fire of unknown origin took place in one of the bins with flames extending 100 ft into the air. Shortly afterwards, contents of other (but not necessarily adjoining) bins suddenly and intermittently flared up. Material in all bins soon became involved and 159,000 lb of *Zr* were consumed. The heat was sufficiently intense to crack windows and ignite wood located over 150 feet away. Particles of burning *Zr* were carried over one-quarter of a mile through the air. [This took place at Bettis laboratory, Pittsburgh.]

¶ About 5 years ago some water-wet scrap *Zr* powder in wooden barrels was placed in outside storage pending development of scrap-recovery processes. During the next several years, a few minor spontaneous fires broke out in this material. In January 1956, the material in several deteriorated wooden barrels was wet with water and repackaged in steel drums.

In May 1956, employees working in the area noted that one of the steel drums lying on its side contained a black material "similar to carbon dust." Just exactly what happened there is uncertain, but a spontaneous explosion occurred accompanied by streaks of red fire with black smoke extending 100 ft into the air. A pronounced concussion wave was noted and sound of the blast heard several miles away. Two employees were killed, one having been blown 80 ft through the air, and a third lost an arm.

The drum contained *Zr*, probably in the form of a fine powder.

Using extensive precautions, the remaining drums of scrap *Zr* were subsequently burned. During this operation, one of the drums exploded in a manner shown in Fig. 4. [This incident took place at the Y-12 area, Oak Ridge.]

¶ Two men died and two others were seriously injured in 1954 in a spontaneous explosion initiated during removal of the friction-top lid from a polythene-bag-lined, one-gallon metal can containing *Zr* powder 16% wet with water. A ball of flame enveloped the entire area, accompanied by a definite concussion wave.

¶ A 2-lb sample of carbon-tetrachloride-moistened powdered *Zr* was placed in a glass flask, vacuum applied, and the flask very gently heated with a Bunsen burner. The *Zr* suddenly began to heat up and detonated with a blinding flash. The explosion was attributed to a small amount of water.

Uranium Incidents

¶ In June 1956, three flat U plates (¼ × 3 × 14 in.), made by powder metallurgical means, were observed to have "blown up" to approximately 3-in.-diameter rods. The "rods" were removed from the building awaiting disposal. The following morning, one of the plates exploded and "took off like a rocket," hitting a tree 30 ft away. The remaining plates were pierced with bullets but no explosions occurred. It was the opinion of company personnel that the plates had not been pressed to full density and that there was an incomplete decomposition of the hydride in the U powder, causing a build-up of internal hydrogen pressure.

¶ In January 1955, an attempt was made to roll two 1,000-lb U slabs to 0.01-in.-thick strip. After initial heating to 1,150° F in a lithium-carbonate–potassium-carbonate bath, several 30% reductions were made by rolling. It was observed that heavy work passes had caused overheating. The strip, then ¾ in. thick, was cooled to 1,200° F before entering the four finishing stands. The strip again excessively heated during the next three reductions and became so ductile on entering the fourth stand that it pulled into two parts and a cobble resulted. The strip at this stage was cherry red, but by the time it had been removed to the mill floor it was observed to increase in temperature to a white heat followed by melting and burning.

¶ In February 1956, a technician was attempting to roll a plate consisting of *Zr*-clad U, which, in turn, was clad in a low-carbon-steel jacket. During preheating, the furnace temperature control (which had been set to 1,450° F) failed, allowing the temperature to rise to 1,800° F. During subsequent rolling, molten Fe-*Zr* eutectic alloy within the steel jacket was forced to one end of the strip where it burst into flames as it sprayed out over an area approximately 10 ft wide, 10 ft high, and 25 ft long. One employee was seriously injured.

¶ In the early program for the large-scale manufacture of metallic U, fine powder was allowed to collect under roughly 25 ft of water. At approximately one-month intervals, and without prior warning, a geyser about 30 ft high would suddenly develop over the powder and then immediately subside.

¶ A series of cases is known in which massive pieces of metallic U, Pu, and Th have displayed unusual pyrophoricity, e.g., spontaneously igniting at room temperature. Spontaneous fires in U chips are, however, much more common and in one case ignition occurred 6 months after the chips had been placed in storage. One investigator of spontaneous fires in briquetted U chips opened a drum filled with briquettes that had been in outside storage for several weeks. After noting that the drum contents were normal and at approximately room temperature, he was warned by an operator to stand back. A few seconds later, a flame shot to a height of about

25 ft and then immediately subsided. Upon reinspecting the drum interior, he noted that all of the briquettes were at an incandescent temperature.

¶ A series of incidents have been experienced in which U and Ti alloys have displayed explosive surface films following acid treatment (*12, 14*). Studies at Argonne National Laboratory showed that such explosions could be averted through use of adequate fluoride ion concentrations in nitric acid etching baths. Witnesses have described metal-surface explosions of this type as involving a brilliant flash of white light, accompanied by a sound similar to that of a 22-gage rifle shot.

Thorium Incidents

¶ For several years scrap Th powder had been disposed of by burning in successive small amounts. In July 1956, employees were engaged in burning scrap Th powder that had previously been washed with several aqueous solutions and vacuum-dried 3 days earlier. Some of the Th was placed in a special hood and ignited without incident. An employee took a "golf-ball-size" piece of Th from a metal pail containing 30–40 lb, replaced the pail lid, and placed the piece on a small Th fire. An immediate sharp explosion blew the employee 20 ft across the room. Almost immediately, a second blast involving the Th in the pail was accompanied by a jet of orange fire and a big cloud of dust. A third explosion occurred in a nearby vacuum dryer containing about 7 lb of moist Th powder. One employee suffered fatal burns, while three others suffered serious injuries. The extent of property damage is evident in Fig. 3. [This took place at Sylvania Electric Company's Metallurgical laboratory, Bayside, N. Y.]

¶ In preparing an experimental charge for making metallic Th in a reduction bomb, a mixer was being used to blend metallic calcium, dry zinc chloride, and dry thorium fluoride. After several revolutions of the mixer, the operator opened the mixer vent and, noting that dust and gas were escaping, decided to call his foreman. A second operator closed the vent, started the mixer, and soon heard a rumbling noise, followed by a sudden burst of flame covering a 45-deg angle and extending parallel to the floor for 40 ft. Of the eight persons injured by the blaze, two subsequently died. Reason for initiation of the reduction reaction in the blender is uncertain and unprecedented.

It was subsequently found that the calcium used was particularly reactive. In one test a marked, but unexplained, temperature rise occurred when some −50 mesh calcium fines were left standing in an argon atmosphere.

Miscellaneous Incidents

¶ On June 16, 1954, employees of a non-AEC high-energy-fuel laboratory were sampling 15 drums of "bag fines" Mg powder, which were opened in a special room that had been purged with nitrogen until the oxygen content had dropped below 1%. During sampling of the fifth drum, the powder ignited suddenly. The flame shot out from the drum, immediately subsided, and the operators left the room after replacing the drum cover. From an external observation window, the employees noticed a gradual darkening of the drum's exterior, moving down to within 2–4 in. of the drum bottom. The following day the drum was opened and contained a definite yellow coloration, which was presumed due to formation of magnesium nitride.

¶ A massive block of metallic barium was cut into ¾-in.-square pieces while submerged in kerosene. During attempts to remove residual kerosene with carbon tetrachloride (an operation that had been performed many times before without incident), violent reaction dispersed glass fragments and burning barium over the immediate area. Similar explosions have also been suffered when Na, U, and Zr were treated with carbon tetrachloride.

¶ Trouble had been experienced in getting a Kroll process reduction of $ZrCl_4$ with Mg to go to completion. When the furnace was opened up, a slate grey material was noted on the surface, which was thought to consist of Zr, Mg, and MgCl. A sample of this material, roughly ¼ in.-thick and 8 in.-square, was removed for test and was totally inert when scratched with a file or hit with a hammer. A piece of the sample melted under an oxyacetylene flame but showed no pyrophoric properties. Samples were then placed in water and slight evolution of gas noted. The following day an attempt was made to further wash the samples in several changes of water. While under 5 in. of water and without any prior evidence of reaction, an explosion occurred that shattered the laboratory bench, threw the technician against the wall, and blew out a window 25 ft away. Portions of the water-washed sample blown to the floor ignited and "spit" when stepped upon. Small samples were subsequently tested and found to contain Mg, Zr, and 1% C.

Crash Program Aims

Objective of AEC's crash program on Zr sensitivity is to determine those properties of the various Zr forms and alloys that affect inflammability and explosiveness, and the reaction mechanisms involved in the sensitization of the metal. The study will assess the hazards involved in Zr manufacture, handling, storage, and shipping. Hf and Ti will be examined on a limited scale to establish relative sensitivity of the three metals.

The experimental approach to the problem will be to determine flammability and explosive characteristics of various types of sponge, process materials, powders and metallic scrap to establish relative standards and regions of sensitivity for the various materials. To do this, tests will determine the sensitivity of the material to friction and impact forces, flame or radiation, temperature and high velocity shock waves under controlled environmental conditions. Detailed studies will weigh effect of particle size, surface area (and, in sponge, density and extent of agglomeration), impurities and process contaminants such as Fe and other metals, salts, carbon, O, N, H, water, etc.

mass and with decreasing particle size.

Several interesting observations have been made of the effect of powder mass on pyrophoricity. Dust obtained by filing a zirconium-titanium alloy never ignited when dispersed over a bench, but always ignited spontaneously whenever small layers were accumulated. Zr powder dispersed over a red hot plate slowly oxidized, while a layer of the same powder thrown on the same plate immediately ignited and burned violently. Small layers of very fine U powder under water appear inert, while larger amounts tend to "ball up" following which spontaneous ignition is virtually certain.

The foregoing and other reported work (*3, 4*) suggest that for a metal powder of particular particle size there exists a definite minimum quantity of metal that must be exceeded for spontaneous ignition. Following the same line of reasoning, any metal capable of reacting exothermically with oxygen should also be capable of spontaneously igniting in air if the metal is sufficiently finely divided and if a sufficient quantity is present. Experimental work (*5*) tends to confirm this suspicion for a series of metals (including iron, copper, and tungsten).

In many respects spontaneous ignition of metal powders is similar to spontaneous ignition of oily rags, while self-sustaining burning of massive metal is more nearly comparable to burning of ordinary flammable liquids and solids.

Powder Explosions

In general, the combustion in air of flammable vapors generates much less heat but a much greater volume of gases than does combustion of powdered pyrophoric metals. Since explosion pressure is roughly proportional to the product of the heat generated and the ultimate gas volume, an increase in explosion pressure is expected if the metals tested contain dissolved gases (notably hydrogen). Comparison of air-metal and air–metal-hydride dust explosion tests (*6*) tends to confirm this suspicion. Maximum explosion pressures attainable upon detonation of air–powdered-metal mixtures are approximately equal to the maximum attainable by detonation of flammable-vapor–air mixtures (*7*).

Vapor or powdered-metal explosion pressures obviously vary with the materials involved, the ratio of mixture

FIG. 4. Flare-up of Zr scrap during disposal operation in May 1956. After two men had been killed and a third lost an arm while attempting to re-crate scrap Zr for removal, it was decided to burn remaining scrap cautiously in outdoor storage area

components, and the initial pressure. With initial mixtures at optimum proportions and atmospheric pressure, maximum explosion pressures are roughly 0–150 psig.

Effect of particle size. Qualitatively, the ease of ignition and explosion pressures attainable with metal dusts decrease rapidly with increasing particle size. The maximum particle size that will just support combustion following dispersion in air has not been adequately investigated. The amount of energy required to initiate explosion of fine metal powders dispersed in air is often surprisingly low (*6*). In some cases the energy involved in dispersing the powder is sufficient to initiate spontaneous explosions.

Oxides Reduce Pyrophoricity

Although pyrophoric metals burn in oxygen, the pyrophoricity of many metals, e.g., U (*8*), can often be dramatically reduced using oxygen. As an example, finely divided iron powder, prepared by hydrogen reduction of iron formate, will often ignite when first exposed to air. If, however, after preparing such powders, the hydrogen is replaced with an inert gas into which small amounts of dry oxygen are slowly fed while the furnace is being cooled to room temperatures, an iron powder is obtained that may be handled in air without ignition. A similar commercial process reduces pyrophoricity of highly porous Ti and Zr sponge produced by the Kroll process.

The ability of oxide coatings to reduce apparent metal pyrophoricity varies considerably among different metals and even among specimens of the same metal. Both the physical and chemical properties of oxide coatings may change markedly with increasing temperatures. Some metals such as Ti and Zr are capable of dissolving large quantities of surface oxides when heated above phase transformation temperatures, while other metals such as Al and U do not absorb significant quantities of surface oxides even when the metal is heated to its melting point.

Several investigators, while admitting that it does not make sense from a thermodynamic viewpoint, have found by test that Zr powders containing up to 25% oxide are more readily ignited than similar powders relatively free of oxides. The role played by surface oxides in the metal pyrophoricity picture is obviously important, complex, often erratic, and confusing.

Much information is available in the chemical literature on the oxidation of metals by oxygen, air, and water. Much is also known about the effects of oxide films on metal oxidation rates. The amount of heat liberated from combustion of specific metals can be accurately predicted, as can many factors influencing the probability of a reaction (such as temperature, pressure, etc.).

Despite this profusion of information, very little is known about the specific sequence of physical and chemical steps occurring during metal burning. Even less is known about reaction-rate variables during intermediate steps preceding and during metal combustion. This is particularly true when moisture and metal contaminants are involved.

The study of many unusual pyrophoric-metal incidents (*12, 13*), indicates apparently several independent mechanisms may contribute to metal pyrophoricity, and that surface oxides, stress, moisture, and contaminants are major facets deserving evaluation.

Moisture Increases Pyrophoricity

Metal pyrophoricity is strongly influenced by moisture. Metals such as Na and K can react violently with water (*9*), as is well known. In the case of U, the high-temperature reaction with steam is much more violent than with oxygen (*10*).

Studies have indicated that the reaction between some metals (e.g., powdered Al or Mg) and water is theoretically capable of producing slightly more explosive energy than nitroglycerin or TNT. Russian scientists reported (*11*) attainment of close-to-theoretical energy releases during tests aimed at preliminary evaluation of the use of water-metal reactions as high-explosives.

Many methods are known for inducing water-metal explosions (*12*). A few violent water-metal explosions have accidentally occurred in industry (notably during arc melting of Ti in water-cooled crucibles). However, the rarity of such occurrences suggests that explosions of this type are only attainable under a very narrow set of conditions. That they can occur at all, however, justifies current AEC research in this area.

Two recent reports (*12, 13*) provide strong circumstantial evidence that pyrophoricity of U and Zr can sometimes be very materially increased by prior quiescent exposure to moisture at room temperature. Research is currently under way to determine the mechanism by which metal surfaces are pyrophorically influenced by water.

Stress Increases Pyrophoricity

There exists fragmentary but impressive evidence that pyrophoricity is increased when the metal is under stress. This stress can be physical or chemical. Uranium lathe chips, for example, appear to be very much more susceptible to spontaneous ignition than annealed metal of the same dimensions in sheet form. Several incidents (*14*) suggest a connection between stress and metal-surface explosions in nitric acid. Sudden release of elastic

Combustion of Metals: Solids vs Powders

Property compared	*Powder-to-solid ratio of property**
Combustion surface area	13,300
Metal mass involved	0.524
Total-surface: total-mass ratio	25,400
Fraction of total surface area exposed to external surroundings	0.000118

* Based on cubic packing of spherical particles 1μ in dia.

At Blackout Prizes

7TH SPORTS RACING

strain can, under suitable conditions, cause adiabatic heating of metallic Ti fragments to their ignition temperature in air (*15*).

That pyrophoricity is increased by metal brittleness would be expected. For example, brittle alloys are used in lighter flints.

Na-K and Ti-Zr alloys are more pyrophoric and have lower melting points than the pure constituent metals. This suggests that metal contaminants that lower melting points can, in some cases, add to metal pyrophoricity.

Sheet Zr has ignited while under nitric acid when the sheet accidentally touched the graphite container. This suggests that surface contaminant occlusions can (in part through electrolytic effects) substantially alter metal pyrophoricity.

Significance of Hydrogen

The metal fire and explosion vagaries studied covered a wide range of temperatures, metal purities, atmospheres, surface-to-mass-ratios, etc. The only factor that appeared to be commonly involved in all of these incidents was hydrogen, i.e., all of the metals involved had either been made by hydride decomposition (and could therefore be suspected of retaining some hydrogen) or had at some time been exposed to water in some form.

The evidence of the significance of hydrogen was often dramatic. Thus, U chips often ignited in moist air but seemed nonpyrophoric in dry air. Metal spontaneously ignited (sometimes even in the absence of air) after prolonged storage under moist argon or water. Hydrogen concentrations on machined U surfaces sometimes ranged up to 50 times the published room temperature solubility of hydrogen in U. Brittle, pyrophoric uranium hydride has been identified following U exposure to water, etc.

While it is known that hydrogen on and below the metal surface is not the sole cause of pyrophoric anomalies, it is reasonably certain that it is a major common contributing cause. The various mechanisms by which hydrogen derived from water can enter and migrate within a metal (*16, 18*) are of less immediate interest than the ultimate effect of such hydrogen on pyrophoricity and the fate of the oxygen left after hydrogen removal from water.

It is thought that the principal effects of hydrogen on metal pyrophoricity include increasing internal stress (*17, 18*), promoting metal surface fragmentation (in part through effects on brittleness, accentuation of grain boundary defects, and through subsurface gas evolution under heat), and reduction of surface-oxide protection of the metal.

Moesel's theory. According to a theory proposed by F. C. Moesel, three possible reactions occur: (a) metal plus moisture form metal hydride and hydrogen peroxide; (b) metal plus oxygen, in the presence of moisture, form metal oxide and additional peroxide; (c) metal plus hydrogen peroxide form metal peroxide or at least associate with each other by physical adsorption or absorption, which makes this reaction imminent. A metal fire in the absence of air would be the reaction of metal peroxide (or metal and hydrogen peroxide) with adjacent metal to form metal oxide with a liberation of heat. With a sufficient buildup in metal peroxide concentration, this reaction could be explosive. In the presence of air, the dispersion resulting from the primary explosion would result in a secondary explosion involving the oxidation of not only the earlier formed metal hydride, but also of the residual metal in the dispersed particles.

The general theory involved in spontaneous ignition of metal powders has been previously discussed. However, a number of incidents show that moist metal powders can, under some conditions, literally explode (either in the presence or absence of air), instead of simply igniting and quiescently burning. Mixed hydride and peroxide on the metal surface is one of several possible high-energy sources capable of spontaneously and very rapidly raising powder temperatures to a high degree.

In the discussion of massive-metal pyrophoricity theories, several mechanisms were covered relative to fragmentizing of heated metal surfaces. The same principles are thought to be even more applicable to metal powders.

Finally, the Russian experimenters obtained high-energy water-metal explosions under conditions comparable to hot fragmentized powdered metal (*11*). Thus, both theory and experience justify considerable precautions when handling or heating moist, finely divided powders with the degree of concern increasing with increasing quantities and decreasing average particle size.

Experience and experiments have shown that when water contacts molten pyrophoric metals, rapid generation of steam is, under quite narrow conditions, occasionally accompanied by violently explosive water-metal reactions. In the case of high-melting-point pyrophoric metals, experiments have shown that when water-metal explosions are attained, only a small percentage of the molten metal reacts with water. From this fact it can be assumed that the critical conditions are disrupted during the explosion. It is thought that during that very brief interval in which the very-high-temperature liquid metal can remain in contact with water, a combination of mechanical and exothermic chemical forces cause rapid spewing of finely divided and exceedingly hot metal particles into water (*12*). The basic mechanism involved in liquid metal-water explosions is viewed as being very similar to, but more severe than, the moist-metal-powder explosions.

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THE PUBLIC AND NUCLEAR RISK:

Lessons Learned from a Pyrophoricity Incident

In a NUCLEONICS interview, Merril Eisenbud, the manager of AEC's New York Operations Office, discusses the broad problem of public awareness—and public acceptance—of nuclear plant hazards, real and fancied.

The problem became an acute one for the nation's largest city when, on July 2, 1956, a lump of caky thorium powder exploded in the metallurgical laboratory of Sylvania Electric Co.'s nuclear division at Bayside, N. Y. Near-hysteria over a "radiation hazard" proved entirely groundless, but pointed up the problem of preparing the public to accept nuclear risk situations in the same way that ordinary industrial and chemical risks are accepted.

Merril Eisenbud is well qualified to discuss this subject, having already been a practicing specialist in industrial hygiene for 11 years before joining AEC's Health and Safety Laboratory in New York. He became its director in 1949, and in 1954 manager of New York Operations as well. He is responsible for AEC's national fallout monitoring system, teaches industrial medicine at N.Y.U., and advises on toxicology and on atmospheric and industrial hygiene.

Mr. Eisenbud, do you consider the laboratory accident at Bayside, Long Island, in July, to have been a serious break in the Atomic Energy Commission's remarkable safety record?

The Atomic Energy Commission is proud of its safety record. Any accident that results in the injury of people or in the death of a man is a serious break in our performance in this respect. On the other hand, I think one ought to note that this was not an accident of the type about which the AEC and the public has been mostly concerned—namely, an accident that might result in exposure of people to radiation, and in the contamination of areas with fissionable materials or fission products. This accident involved thorium, which is a slightly radioactive material, but the character of the accident was largely that of a chemical accident.

What exactly did take place at Bayside?

For some time the laboratory had been engaged in work involving finely divided thorium, as a metallic powder. Many metals, when they exist in finely divided form, are pyrophoric. It is customary, prior to ultimate disposal, to oxidize these powders under controlled conditions so that one ends up with an inert oxide rather than the original pyrophoric material. This operation is performed in an enclosure. It's a very simple operation—literally the burning of the powder at a very slow rate.

On this occasion, for a reason that we don't quite understand, there was a sudden explosion of a lump of finely divided thorium about the size of a golf ball. It's possible that the explosion was caused by impurities in the thorium. In any case we are not exactly sure what it was about this material that was different from that which had been successfully oxidized over a long period of time.

There was a chain of three explosions. The original material exploded in a dry box provided for this operation. This detonation resulted in the explosion of about 40 lb of powdered thorium stored in the same room in which the operation was taking place. Then there was a third explosion that may have involved dust distributed throughout the ventilation system, or may have included other powdered metals stored in various places in that particular department. All these explosions took place within a few seconds of each other. Four men were seriously injured—one ultimately died of approximately 60% third-degree burns. Explosion was severe but there was no fire. About $25,000 damage was done to AEC equipment and building; the contractor lost over $100,000.

How do the risks inherent in this type of operation compare in severity with the risks in other types of nuclear energy activities, such as reactor operations?

In the nuclear energy industry generally, you cover the entire spectrum of risk. Many of the things we do in atomic energy installations don't involve radioactive materials at all. They involve all sorts of mechanical and chemical procedures

that are provided in support of nuclear activities. At the other end of the spectrum, of course, you have a large power reactor, or perhaps a chemical separations plant in which there is a very large potential for the release of radioactivity. As you imply, the potential risk in this particular operation was very much less than what we would have to consider where large amounts of radioactive materials were being handled, or where a large reactor was being operated.

Such large-scale operations would, under AEC's safeguard procedures, presumably be much less likely to be located near a large population center as was the case here, would it not?

As our knowledge in the reactor field increases, more and more reactors will be placed closer and closer to centers of population—already certain research reactors are being constructed in population centers. The development of the atomic energy industry depends on our ability to learn how to construct reactors in population centers with the same degree of assurance with which we now construct conventional power plants in those centers.

How successful was advance planning for a contingency such as the Bayside incident?

This has to be discussed from two points of view: first, the advance planning that goes into a plant emergency plan *per se*, and second, the advance planning that contemplates the problems arising out of community reactions.

The plant emergency plan generally worked well. The proper agencies—Atomic Energy Commission, fire department, police, and so on—were notified immediately; there was immediate evacuation of employees from the affected area, and there were local rescue operations and first-aid procedures that we believe were adequate to take care of the emergency as it then existed.

There was one serious shortcoming in the plant emergency procedure which I think may be true of a great many emergency procedures and may be worth taking note of. There was adequate provision for evacuation of the employees, but there was no plan to assemble them and keep them grouped until they could be briefed on what had actually taken place. When the employees were evacuated from the laboratory, they were free to roam about the neighborhood. Obviously they could only speculate on what had happened, and their speculations to the policeman on the beat, the neighbors, and members of their own families, in all probability became the sources of many of the unfounded rumors that began to spread through the plant area. I think it would therefore be important in any disaster plan to assemble the employees long enough to brief them on just what did happen, so that they can give more reliable information than that based on their speculations in the absence of good information.

There's another aspect of a plant disaster plan that is very difficult to deal with, particularly in the case of a small plant. This has to do with the large number of people who descend to the scene of emergency, for various reasons. Within a few minutes of the Bayside accident, the fire department, police department, a press corps, the health department, the state labor department, the AEC, the FBI, local civil defense officials, and the U. S. Army all sent representatives to the scene of the emergency. It's obviously not feasible for any relatively small organization as existed in this case at Bayside to deal efficiently with so many people all wanting information at the same time.

As regards the community reaction, I think we learned a great deal. No educational program had been undertaken in this community, and perhaps this was short-sighted. On the other hand, neither the contractor involved nor the AEC had any reason to believe, prior to the incident, that near-hysteria would develop from an accident of this kind.

How effective was the work and the cooperation of the various agencies at the scene of the accident?

To the outsider it might appear that the presence of representatives of so many municipal and state departments would tend to result in a considerable amount of overlapping. Actually, the various facets of the problem that arise in an emergency of this kind are pretty well assigned to various departments and I think that each of them understands what their interest is. It has been my observation in the past they they always work well together. The problem in the particular instance we are discussing was not one of lack of understanding of an individual mission, but lack of understanding of the degree of hazard involved. Because this was true even of some officials present, the confusion was compounded and the spread of inaccurate information was furthered.

What differences are there between the responsibilities of a contractor and those of a licensee? What is the AEC's role in the case of a licensee?

The Atomic Energy Act of 1954 assigns the responsibility for safe operation of the atomic energy industry to AEC. Both contractors of the AEC and licensees are required to adhere to the health and safety standards of the Commission. In the case of a licensee, AEC must be satisfied, at the time of application for a license, that the work to be undertaken is without hazard to the employee or the public. After the license is granted, the licensee is subject to periodic inspection by the Commission to assure that he is complying with AEC's health and safety standards.

What was the reaction in the community after the incident? Was it about what might have been expected?

The reaction in the community was one of fear and of misunderstanding, and although one might have anticipated some of this, I believe it was greater than we had expected. Both the contractor and the New York Operations Office of AEC were deluged with calls from residents asking whether or not they should evacuate the neighborhood. We understand that some residents were advised by local policemen to keep their children off the streets. Newspaper and television accounts placed the injured or "exposed" at all the way from 300 to the accurate figure which was 9. These media emphasized the "secret" nature of the work, the "radiation" hazards, and even mentioned the possibility of "sabotage." Both the contractor and AEC subsequently received letters of protest from resident and property-owning groups. These were, of course, answered fully, and this seems to have gone a long way toward reassuring the neighborhood that the plant does not represent a potential radiation hazard. The plant did

not at the time of the accident—nor will it in the future—represent a potential radiation hazard.

How can lessons learned at Bayside be applied to other kinds of nuclear accident situations?

I suppose this question is directed primarily at the problems that arose because of the community reaction to the accident. It's important that we realize that the public is unable to think quantitatively about nuclear hazards. As far as the public is concerned, radioactivity is dangerous—regardless of the amount involved. People seem to have little awareness of the fact that radioactivity was known prior to World War II, and has in fact always existed. Despite the educational efforts expended by the Commission and other agencies to date, the thought processes still seem to run: atomic energy → bomb → radiation → destruction. I think it would be wise to indoctrinate the residents of a plant neighborhood in the general nature of the work being performed in the plant, and also to give them a realistic evaluation of the potential hazards and a description of the safeguards used to prevent those hazards from materializing.

I cannot emphasize too strongly the need to see to it that fire and police department officials are acquainted with, and understand the nature of, the problems that may arise in a plant in the event of an accident. This need is not peculiar to the nuclear industry. It is customary throughout industry to familiarize the fire department in particular with the hazards that might arise in an industrial fire, especially insofar as chemicals are concerned.

Can you estimate the effect of scare headlines and melodramatic radio and TV accounts used in reporting the Bayside incident?

They contributed to the general hysteria, and the confusion was certainly compounded and prolonged by the misleading statements issued by the news media. It is interesting to note that although New York City has one of the best and largest science press corps, not one science writer was assigned to cover this story. General-assignment reporters were sent by the city desks; they had no background in atomic energy nor any particular leaning toward science. The number of requests for physical examinations received by NYOO from reporters who had visited the scene of the accident has led us to believe that the headlines reflected to some degree the honest fears of the men assigned to cover the story. Although all possible candor was used in responding to inquiries and statements were issued to the media as quickly as the facts were established, uninformed reporting continued throughout the day.

What can be done to indoctrinate the press?

With a large press corps such as we have in New York City, I don't suppose that it is possible to indoctrinate the press as a group separate from the general public. I think that the problem that arose here is one that you face in any emergency. The press wants information within minutes after the accident occurs, whereas it may take an hour or so to develop a factual account of what happened. It is during this interval that effective contact with the press is most essential. Speculation must be carefully screened from facts. An information headquarters at the scene is important: in any emergency beyond that of a routine neighborhood fire, there should be an emergency information headquarters where people qualified to speak on the matter involved would be accessible to news media representatives. To be effective, such a headquarters should be established by the fire and police departments.

What specific things can be done to educate the public to accept atomic energy?

There is a need for intensive indoctrination courses at every level of city and state government as well as with the public at large. Most cities, like New York, have access to talented people. For example, the Department of Hospitals here has a group of very competent physicists who are well versed in the problems that may arise out of developments in nuclear energy. I think that the city should make an effort to tap these home resources to design educational programs for those of their personnel who may be involved in handling incidents of this nature. The AEC has always been pleased to cooperate with any agency that wishes to conduct educational programs. For some years we have, for instance, been cooperating with the New York City Board of Education in conducting training classes for science teachers. We have helped to give teachers information and techniques they can incorporate into their classroom and laboratory work so as to indoctrinate their students in the basic facts of atomic energy and in nuclear physics and chemistry. This type of program has been conducted by AEC all over the country, and I think that there should be more and more use of such programs. Every community should take advantage of the assistance available to it by virtue of the large number of AEC contractors, private industrial projects and universities that have personnel competent in the field of nuclear energy.

What do you think are some of the positive steps that might be taken to improve public understanding of the radiation problem?

I believe that all organizations and agencies—the AEC, the states, private industry, the universities, and any other groups having knowledge in the nuclear field—should assume a portion of the burden of indoctrinating the public in the true facts of radiation, to enable it to distinguish between the inconsequential and the hazardous. Industry and AEC should take the initiative in discussing with the public the possible hazards attendant on any particular nuclear enterprise. All great technological developments introduce new risks, and atomic energy will be no exception. If progress is to be made, it will have to be made with the understanding of the public and the acceptance by it of the fact that a perfect accident record is not possible. Accidents will occur with increasing frequency as the atomic energy program expands and a larger number of installations become involved in nuclear work. With the cooperation of government and industry, these accidents will be minimized, but they cannot be eliminated entirely.

If the residents in a plant area are cognizant of the true nature of the potential hazard before an accident occurs, they will be much more apt to react from reason and knowledge rather than from emotion. In any community where there is a likelihood of an atomic-energy-connected accident, there must perforce be a few people supervising the work who are knowledgeable in the hazards the work entails. If these persons were to appoint one or two of their number to serve as spokesmen and make themselves known to the local city officials and the press corps as a source of assistance and authoritative information, the public reaction could be expected to be in some degree proportional to the danger involved.

What time element would you place on public indoctrination courses—that is, how urgent is the problem? How fast must solutions be found to keep up with the growth of nuclear industry?

The urgent need for a more informed public is obvious from the community reaction to this incident. On the other hand, the psychology of the public, as it relates to atomic energy, is not going to change overnight and the passage of time may be an essential ingredient of the educational process. Every effort expended helps a little bit. Efforts in the educational field must be expanded, but a well-indoctrinated public is many years off, under the best conditions. Lectures, pamphlets, movies, and other educational tools are all useful and should be brought to bear on this problem—but there is no magic formula for its solution.

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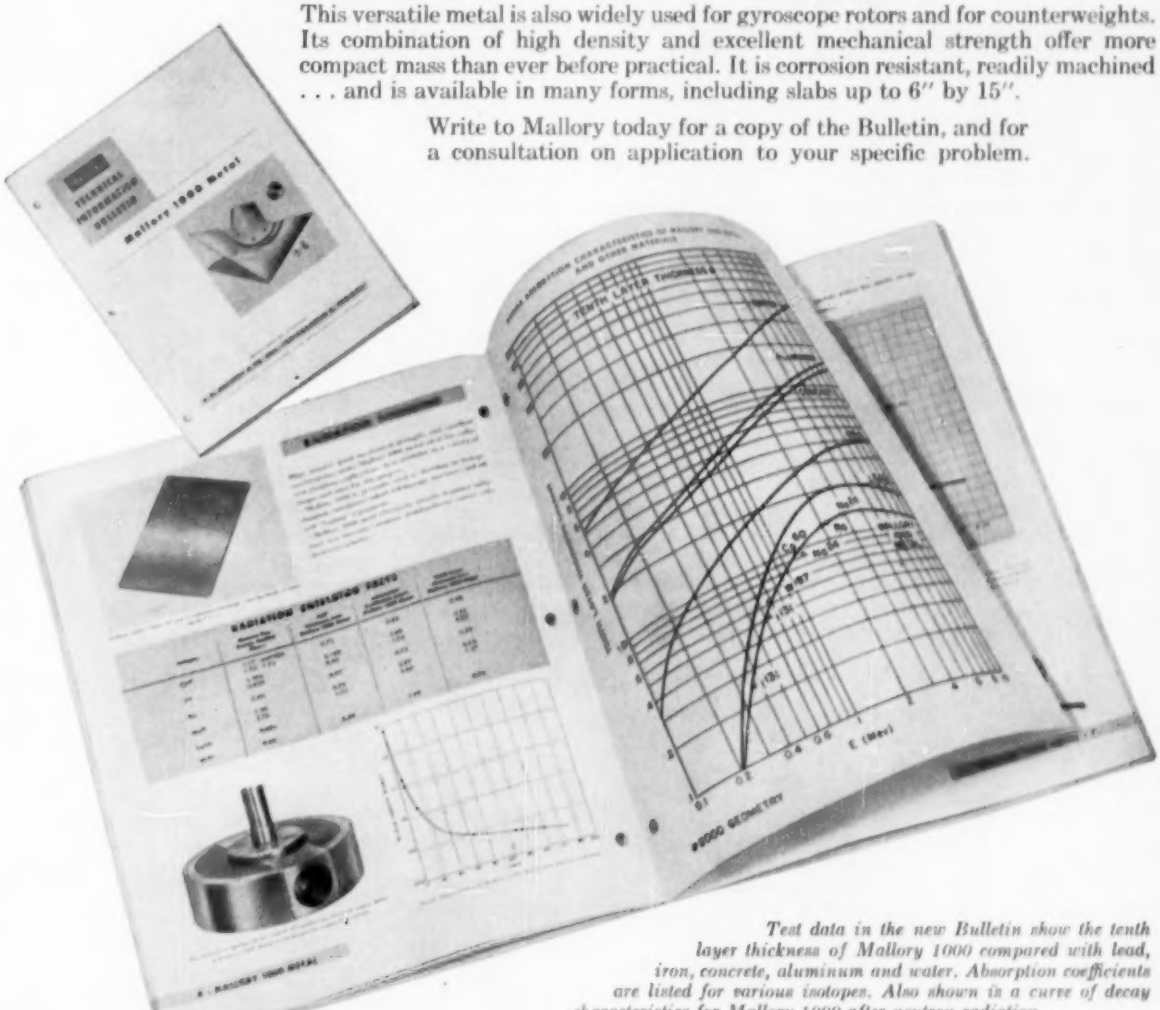

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Device for Generating Radioactive Aerosols

By J. F. PESTANER and L. H. GEVANTMAN
Chemical Technology Division
U. S. Naval Radiological Defense Laboratory
San Francisco, California

Chemically inert, radioactive, solid aerosols (*1, 2*) are useful for studying aerosol behavior. The solid-aerosol generator described here can be applied to fallout phenomena and other air-pollution problems. To avoid the lengthy preparation and handling involved in previous methods we developed the device shown in Fig. 1.

In our application, the generator aspirates a solution containing a thermally unstable iron compound mixed with a trace quantity of $Fe^{55,59}$ into a hot zone where conversion of the salt to the oxide results in an inert, radioactive, solid aerosol.

Particles are collected either by allowing them to settle onto a greased microscope slide or by directing the aerosol through a modified Porton oscillating thermal precipitator (*3*). Particulate size and appearance are examined with a Bausch and Lomb metallurgical microscope (Model CM) and an RCA electron microscope (Model EMU2).

Chemical analysis shows the particles are 97% ferric oxide (*4*).

Performance

Changes in aerosol particle size and appearance were investigated to indicate performance of the device for a given set of conditions: salt concentration, associated anion, oven temperature, gas flow, and aspirator type.

Effect of salt anion. To find the proper salt for our studies, 0.1 *M* ferric-ion solutions of ferric ammonium citrate, ferric oxalate, ferric chloride, and ferric nitrate were adjusted to *p*H 2 and aspirated through the generator with a Dautrebande aspirator. The solid particles collected were examined for uniform appearance, particle-size distribution and iron valence state.

Particle size distribution for each salt as obtained with the optical microscope is shown in Fig. 2. The sphericity of particles obtained from iron ammonium citrate solution resulted in its selection for use in the following investigations.

Effect of concentration. Under reproducible conditions it can be shown that for spherical particulates

$$C_1/C_2 = (d_1/d_2)^3 \qquad (1)$$

where C_1 and C_2 = ferric ion concentration and d_1 and d_2 = particulate diameter.

Solutions of ferric ammonium citrate from 10^{-3} to 10^{-1} *M* in ferric ion were aspirated with the Venturi aspirator. Particulate sizes ranged from 0.01 to 100 μ. A plot of these data in Fig. 3 shows good agreement with Eq. 1.

Effect of variation in oven temperature and gas flow. Temperature variations above the decomposition point of the ferric salts employed had no measurable effect upon particulate size or appearance. Variation in gas flow through the Venturi aspirator from 5 to 7 liters/min resulted in an insignificant decrease in particle diameter.

Size Distribution

The determination of a component particle-size distribution consists of viewing particles in randomly selected areas at a given magnification. A number of overlapping distributions are obtained by sampling at selected magnifications. Each distribution recorded is truncated due to the instrumental limits of resolution, depth of focus, and viewing-field size.

To combine these distributions it must be hypothesized that proportionate populations are sampled. This hypothesis is tested in the following way:

Consider a random sampling of particles made up of $X_1, X_2, \ldots X_k$, where X_1 represents the number of particles of diameter 1, and $1 > 2 > \ldots k$. Suppose these are sampled from a population contained in area A_a at a magnification M_a. An estimate of the ratio of the number of particles of a

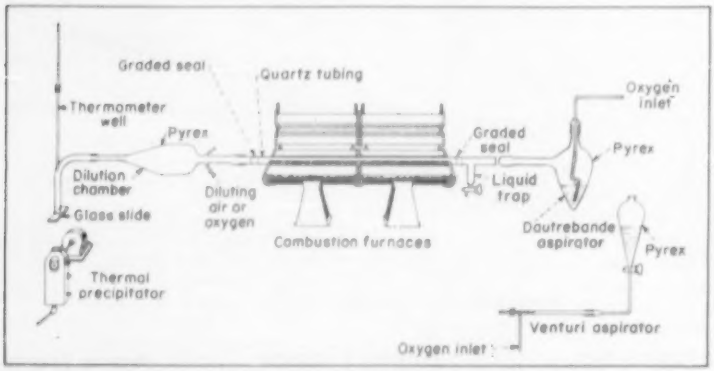

FIG. 1. Solid aerosol generator. Air or oxygen at 30 psig is forced through Dautrebande or Venturi aspirator. Aerosol is carried past trap into combustion zone (2.5-cm-diameter, 1-m-long quartz tube surrounded by two 30-cm furnaces). Temperature ranges from 600° C at ends to 1,000° C at center; gas temperatures are believed to reach about 300° C. Gas velocity through combustion zone is 20 cm/sec with Dautrebande and 33 cm/sec with Venturi. Aerosol passes on to dilution chamber where addition of dry air or oxygen reduces relative humidity and particle density to desired level

specific size i to the total observable particles is given by

$$\bar{P}_{x_i} = X_i/N_a \qquad (2)$$

where X_i = number of particles having diameter i, and N_a = total observable number of particles contained in A_a at magnification M_a.

At a greater magnification M_b and for a proportionately smaller area A_b, a new ratio of particles of size i is obtained and is given by

$$\bar{Q}_{y_i} = Y_i/N_b \qquad (3)$$

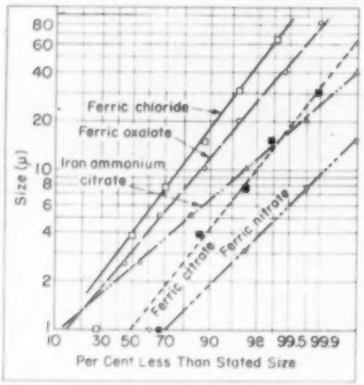

FIG. 2. Effect of salt anion upon aerosol size distribution; Fe concentration, 0.1 M

where Y_i = number of particles having diameter i, and N_b = total number of particles contained in A_b at magnification M_b.

If proportionate numbers of particles of size i have been sampled in A_a and A_b, then

$$\frac{X_i}{N_a} - \frac{Y_i}{N_b - \sum_{k+1}^{n} y_j} = 0 \qquad (4)$$

where $\sum_{k+1}^{n} y_j$ represents those particles that would not be enumerated at the lower magnification because of the instrumental limit of resolution. Thus a test that shows no significant difference in the ratios in Eq. 4 at the $100\alpha\%$ confidence level indicates that proportionate populations have been sampled.

This method of obtaining particle-size distribution and mean diameter was compared with surface-area determinations on a rutile powder using Brunauer Emmett Teller equations (*5*).

Application of the proper factors in the latter approach gives agreement between the two methods to within 1%. Further proof of the efficacy of this method is shown in Fig. 3, where a slope of 2.8 compares with the calculated value of 3.0.

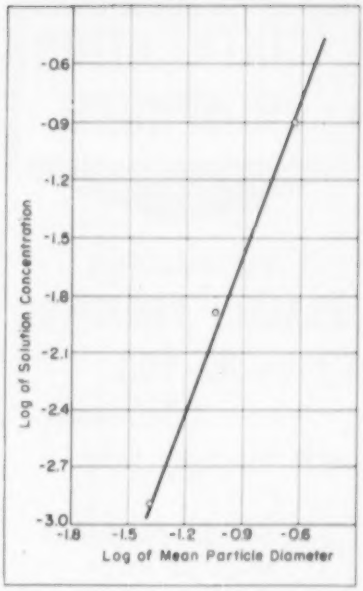

FIG. 3. Effect of solution concentration on particle size

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Scintillation-Detector Doorway Monitor

By D. A. CAMPBELL and L. D. TEST*

Instrument Research and Development Operation
Hanford Atomic Products Operation
General Electric Company
Richland, Washington

To augment routine manual monitoring of personnel clothing for radioactive contamination, the doorway monitor described here was designed to automatically detect hard beta contamination.

Low-gamma-background detectors are required because of the short period the activity is near the detectors. The detector chosen is a Lucite hemisphere covered with anthracene scintillator and attached to a DuMont 6292 photomultiplier tube.

The hemispherical scintillator is preferable because of the directional dependence of a plane scintillator. As shown in Fig. 1, with equal sensitivities for a source in front of the detectors, the hemispherical scintillator has a 4 to 1 improvement in sensitivity to radiation from the sides.

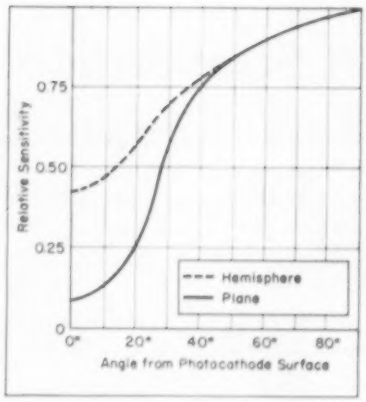

FIG. 1. Effect of angle from photocathode surface on sensitivity of plane and hemispherical scintillators

The hemispheres were attached to the photomultipliers using polyvinylacetate, a transparent thermoplastic material (Bakelite Co.) The hemispheres were then dipped in Lucite dissolved in acetic acid, and powdered anthracene was liberally sprinkled over the surface. After drying, the excess anthracene was shaken off and a second layer applied in the same manner. Finally a protective film of Lucite was applied.

The detector is completed by forming aluminum foil over the scintillator to

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exclude external light and to reflect the light produced in the scintillator. Three layers of ¼-mil aluminum foil were used to prevent the alignment of pinholes in the foil. Black Scotch electrical tape holds the foil in place and is a light shield to cover the remainder of the photomultiplier.

Arrangement of Detectors

The most sensitive monitor is not the one with the most detectors—all the photomultipliers contribute to the background count and only a few are effective in counting a source carried through the doorway. Thus the optimum number is the fewest that can be used while maintaining adequate sensitivity at all points in the doorway. A reasonable criterion is that the minimum allowable sensitivity at any point in the plane of the doorway should not be much less than the sensitivity midway between the sides.

With detectors at 1, 3, and 5 ft from the floor along the sides of the doorway and one overhead at 7 ft, sensitivity is satisfactory. The arrangement is shown in Fig. 2.

Circuit

The detector outputs are combined in an additive mixer that provides for gain-equalization adjustments. The pulses are then fed to a linear amplifier and discriminator for rejecting background pulses, and then to a counting-rate meter. The meter is equipped with an alarm circuit that can be adjusted to operate a light and buzzer at any desired counting rate. An Esterline-Angus recorder is also connected to the meter.

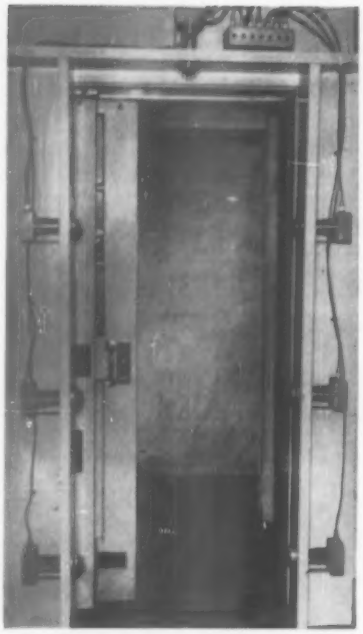

FIG. 2. Doorway monitor installation. Metal guards protect foil covering on scintillators

Performance

The normal background for a doorway monitor is adjusted to 200 cpm. Since the counting-rate meter must respond rapidly, considerable meter fluctuation results. This requires the alarm to be set at 400–500 cpm to avoid operating on random fluctuations.

A 0.5-μc source of 3.5-Mev beta radiation reliably trips the alarm when carried through the doorway at a normal walk.

* * *

This article is based on a paper presented at the annual meeting of the Health Physics Society, June 26, 1956.

A Scintillation Counter for Soft-β Paper Chromatograms

K. STEENBERG* and A. A. BENSON†
Radiation Laboratory, University of California
Berkeley, California

We have developed a large-diameter scintillation counter useful for measurement of the soft beta emitters C^{14}, S^{35} and Ca^{45} in radiochromatograms. Accurate radioactivity measurements on paper chromatograms demand uniform absorption and geometry corrections. Previously, large-diameter end-window G-M tubes were used to minimize errors due to variations in shape and size of the radioactive area but this was not entirely satisfactory (*1*).

*On leave from Isotope Laboratory, Agricultural College of Norway, Vollebekk, Norway.

† PRESENT ADDRESS: Department of Agricultural and Biological Chemistry, The Pennsylvania State University, University Park, Pennsylvania.

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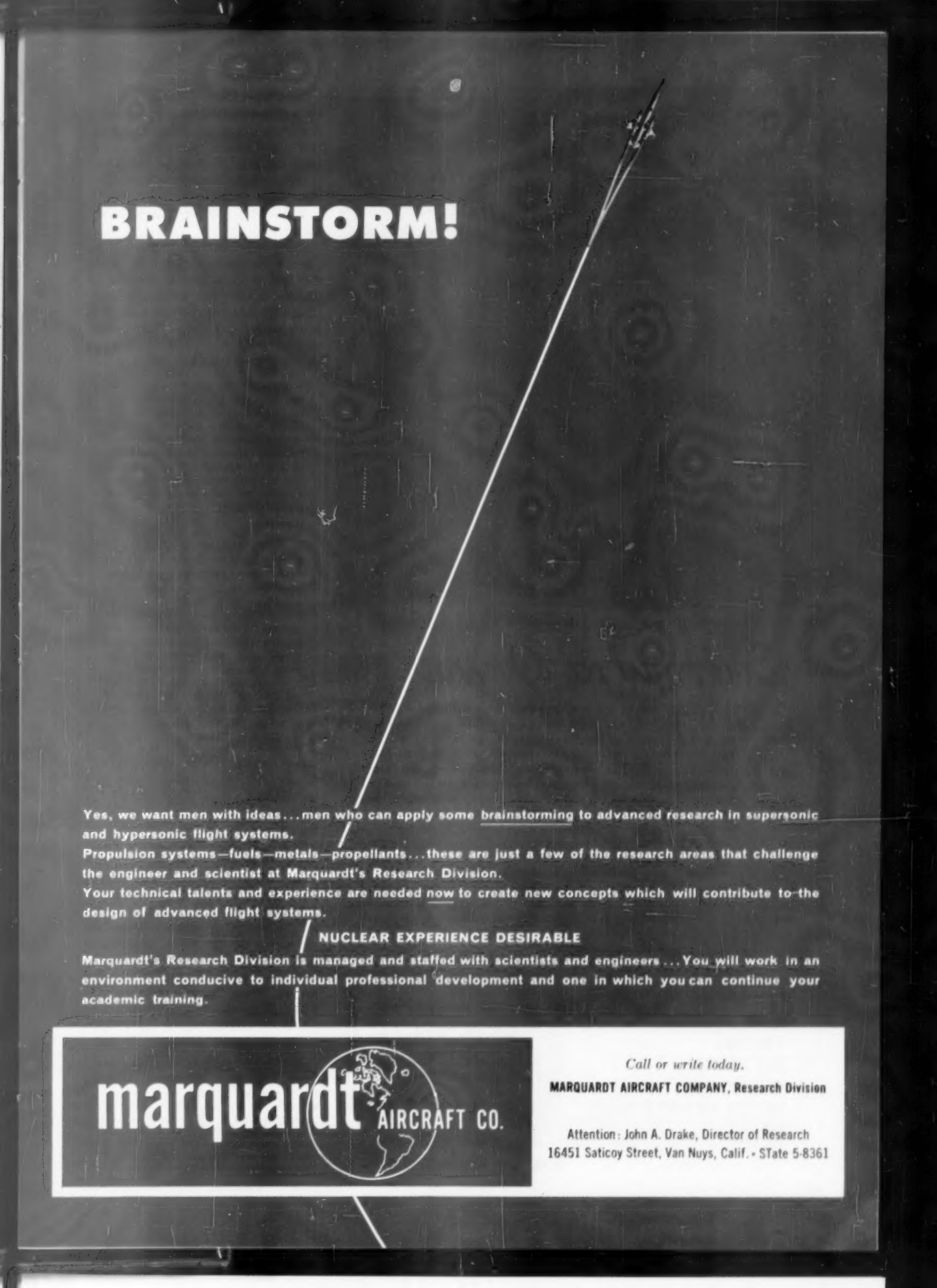

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Counters. One-mil-thick, 2¼-in.-dia terphenyl-polystyrene scintillators‡ were prepared by compression between two glass plates at the softening temperature (*2*). These were attached to standard photomultiplier tubes, DuMont 6292 (2-in.), with high-viscosity optical silicone oil (Dow Corning 200 fluid).

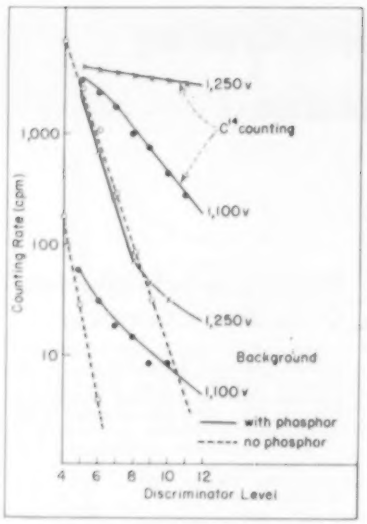
The plastic scintillator, photomultiplier tube and preamplifier were mounted in an aluminum cylinder so that the system was sufficiently light-tight when standing on a chromatogram in a semidarkened room. The counter may be safely moved in the light when the high voltage is off.

> Attempts to allow operation in the light and to increase efficiency by vacuum aluminizing of the highly polished scintillator surfaces were unsuccessful. The resultant opaque, reflective coating was expected to transmit the radiation and enhance the pulse height generated by the scintillator and photomultiplier. However, coatings less than 0.1 mg/cm² did not transmit C^{14} betas as effectively as did an applied aluminum foil of 2–3 mg/cm².
>
> We were unable to explain this phenomenon. It is apparently not due to a poisoning of the scintillator surface. To check this possibility we dissolved the aluminum surface and found the clean plastic quite as effective as it had been before it was aluminized.
>
> For chromatograms of isotopes with energetic radiations, such as P^{32}, the aluminizing technique did serve the desired function.

The counting rate for this counter under proper voltage and pulse discrimination was 70–80% higher and background was 50% less than for a similar-size, mica-end-window G-M counter (2.25-in. dia, 1.5 mg/cm²). Response was uniform over the entire area except near the edges. This property can be tested with a small light source when the phototube is chosen.

Results. The figure shows the variation in counting rate with discriminator setting for C^{14} at two photomultiplier voltages. Background counts, with and without phosphor, coincide for the lower discriminator settings. The activity measured was a C^{14} sample on Whatman No. 1 filter paper, which gave 1,800 cpm with the large-

‡ The polystyrene phosphor, containing 3–5% terphenyl, had a peak response at 4,150 Å. It was prepared according to the method of Dr. Louis Wouters of this laboratory, Livermore Site. We are indebted to Mr. Richard Perkins and Mr. Arthur Hartwig of this laboratory for the application of this technique.



COUNTING CHARACTERISTIC for C^{14} sample. Upper curves are for 10,800-dpm sample, lower curves are background

diameter, mica-window G-M counter with an 80-cpm background. Phosphor thicknesses of 1–10 mils gave identical efficiency, while a 100-mil phosphor was less efficient.

For counting P^{32} areas on paper the thicker phosphors are more efficient. The longer range of the P^{32} beta results in higher pulses and requires lower tube voltage which further reduces the background.

As shown in the figure, most of the background arises from the tube noise. The use of two phototubes with a coincidence circuit did not compensate for the inherent optical losses.

* * *

This work was done under the auspices of the U. S. Atomic Energy Commission and partially supported by the Norwegian Scientific Research Council.

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Alpha-Gamma Coincidence Counting for Flow-Counter Calibration

By W. S. LYON and S. A. REYNOLDS
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Alpha-gamma coincidence counting is a new absolute method for determining the efficiency of an alpha counter. We have applied it to the calibration of flow-type proportional counters.

Early workers (*1–4*) showed that backscatter raised the efficiency of 2π counter setups above 50%. In all such work it was implicitly assumed that self-absorption was negligible and that the calculated calibrating geometry was correct.

At least two advantages result from the application of 4π alpha-gamma coincidence counting to the standardization of an alpha source.

1. Being an absolute method, it does not require any assumptions about counting efficiency.

2. Any effects, such as self-absorption, which might reduce the counting rate, are detectable. They would show up as a difference between the 4π alpha and the 4π coincidence-determined counting rates.

The main advantage of the coincidence method is that in calculating the absolute disintegration rate of the source, the efficiencies of the counting setups cancel out. Where the gamma rays are prompt compared with the resolving time of the counters ($\sim$1 μsec), the absolute disintegration rate of the source is obtained by simply multiplying the observed alpha count by the observed gamma count, and dividing this product by the observed coincidence count.

The efficiency of the alpha counter is the observed alpha count divided by the disintegration rate of the source thus determined. If the 4π counter is

Relation to Beta-Gamma Coincidence Counting

Although 4π alpha-gamma coincidence counting has not been reported in the literature before, it does not differ in principle from beta-gamma coincidence counting (*6*). Such beta counting could be increased in efficiency by extending it to 4π beta-gamma coincidences. This can be done by merely replacing the usual beta counter with a flow type, 4π proportional counter.

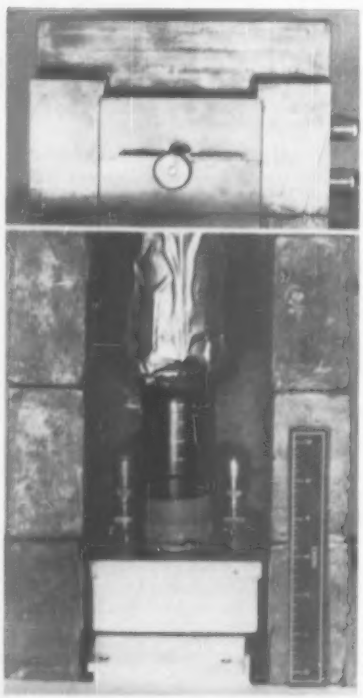

FIG. 1. Counter arrangement showing 4π alpha flow counter above NaI gamma detector

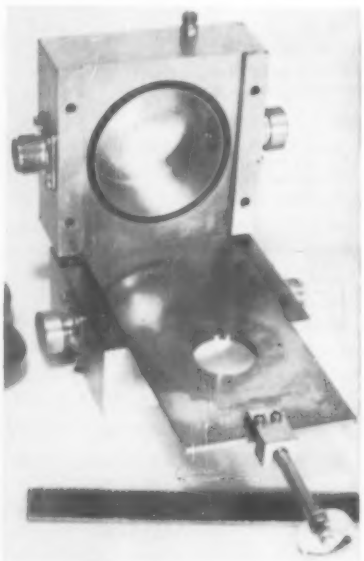

FIG. 2. Detail of 4π alpha flow counter and film mount

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Type R50 (±.002% at 15° to 35°C)
Double triode and 5 pigtail parts required
Input, Tube heater voltage and B voltage
Output, approx. 5V into 200,000 ohms

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Accuracies:—
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Type W2003 (±.005% at —65° to 85°C)
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Size, 8" x 8" x 7¼" High
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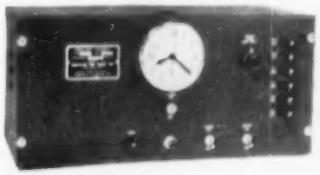

Size
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Output: 115V
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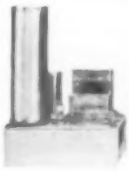
Input, 115V (50 to 400 cycles)



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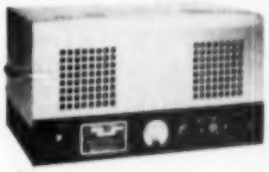

Size, with cover
10" x 17" x 9" H.
Panel model
10" x 19" x 8¾" H.
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Frequencies: 50 to 1000 cycles
Accuracy: (±.002% at 15° to 35°C)
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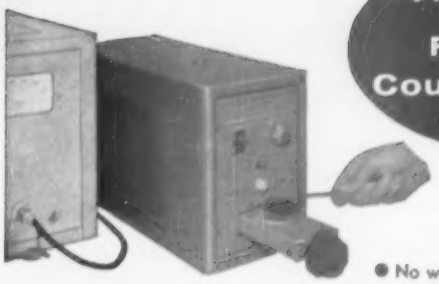

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truly 100% efficient, the observed alpha count and the disintegration rate of the source should be identical.

While Pu^{239} is the alpha source of greatest interest, it cannot be used for alpha-gamma coincidence counting since it has less than 1% gamma radiation associated with its decay. Am^{241}, which has alpha energies only 8% higher than Pu^{239}, can be used since its decay proceeds ~80% through a 60-kev level in the 6×10^{-8}-sec Np^{237m} daughter (*5*).

Equipment

Figures 1 and 2 show our arrangement, a 4π alpha flow counter with a NaI gamma detector in position directly below and adjacent to it. The gamma detector is a 3 × 3-in. NaI(Tl) crystal mounted on a 3-in. DuMont photomultiplier tube. In operation, the entire assembly is surrounded by lead.

Pulses from the 4π counter are fed through a delay line into a coincidence mixer and then to an alpha scaler. The NaI crystal feeds gamma pulses from the 60-kev gamma region (as selected by a single-channel analyzer) through another delay line into the coincidence mixer, and then to a gamma scaler. Coincident alpha-gamma events are recorded on a coincidence scaler. The delay lines equalize the delays in both detecting systems.

Procedures

Americium-241 that had been thoroughly purified from high-level fission-product waste was used as a source material. Aliquots of this slightly acid solution were evaporated under vacuum to dryness on thin (50 $\mu g/cm^2$) laminated formvar-polystyrene film that had previously been rendered conducting by evaporating 12 $\mu g/cm^2$ of aluminum on the surface.

Samples were placed in the 4π counter and voltage plateaus obtained. The alpha counting voltage was set at 2,300 volts.

The active sources were then individually counted in the alpha-gamma coincidence assembly and the absolute disintegration rate of the source calculated as described above.

The source mount holder used with these thin films causes a 3% geometry loss. The expected loss was calculated from the physical dimensions of the source mount and was verified experimentally. For the 4π alpha flow counter, the corrected observed count-

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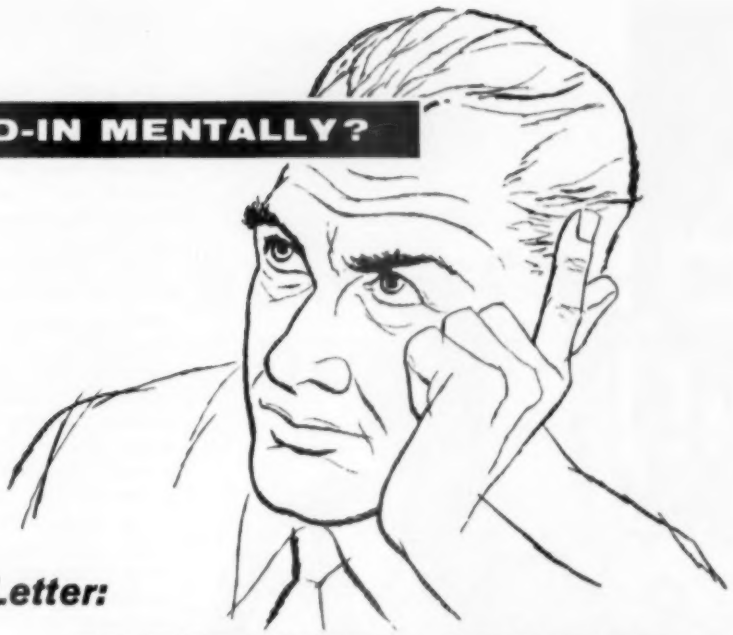

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ing rate and the calculated absolute disintegration rate were identical in every instance.

In addition, each side of the alpha source was counted individually by disconnecting one-half of the alpha counter; these 2π alpha-gamma coincidence data also yielded the previously determined absolute disintegration rate.

Aliquots of the Am^{241} solution were then evaporated to dryness on polished platinum and stainless-steel discs. These were inserted in the counting assembly and 2π alpha-gamma coincidence counting data obtained. The absolute disintegration rate of the stock solution calculated from these readings checked the polystyrene-mount 4π and 2π coincidence data. Thus, these individually and absolutely calibrated platinum- and stainless-steel-mounted Am^{241} sources were available for geometry determinations of other 2π alpha flow counters.

Using these sources as standards, the efficiency of a 2π windowless flow proportional counter was investigated. For the platinum backing we obtained $51.26 \pm 0.13\%$ efficiency, which is in excellent agreement with the 51.3% obtained by an early group (*4*), and in fair agreement with the 51.6% predicted by Crawford (*3*). For the stainless steel backing we obtained $50.20 \pm 0.13\%$ efficiency.

To further verify these values, a second source of Am^{241} was obtained by "milking" Am^{241} from its Pu^{241} parent. Since the Pu-241 had been purified, the Am^{241} was sure to be isotopically pure. (In Am^{241} obtained from fission product solutions there might be traces of Am^{242}.) Data from experiments using this solution agreed with those obtained previously.

* * *

Thanks are due to F. L. Moore who purified the Am^{241} solutions used.

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6. A. C. G. Mitchell, *Revs. Mod. Phys.* **20**, 296 (1948)

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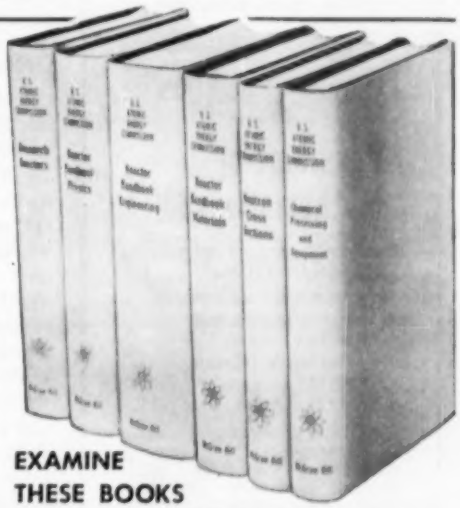

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Laundry Monitor for Alpha Contamination

By F. D. RYDER
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E. I. du Pont de Nemours & Co., Aiken, South Carolina

We needed an instrument to monitor laundered protective clothing for plutonium contamination. The hand-held survey instruments that were available had small sensitive areas and were therefore inadequate for a quick survey of large garments.

Specifications required the monitoring instrument to detect in approximately twelve seconds whether a laundered coverall had more than 500 dpm plutonium contamination on its front surface. The instrument was to be used by unskilled operators.

We developed a two by five foot alpha particle detector to meet this need. The alpha radiation from the plutonium on the garment surfaces is detected by eight large zinc sulfide phosphors viewed by 5-in. photomultipliers.

The complete laundry monitor includes a detector table and a control unit.

FIG. 1. PLUTONIUM CONTAMINATION MONITOR is open while operator places a coverall to be monitored in the garment recess

Detector Table

A recess, two inches deep, was built into the top of a metal table to hold the garments to be monitored (Fig. 1). Eight alpha-sensitive units were placed underneath a heavy metal screen at the bottom of the garment recess. The lid was lined with G-M tubes, which were used with a counting-rate circuit to monitor the clothes for beta-gamma contamination. The beta-gamma system consisted of conventional devices and is not discussed in this report.

Each of the alpha detectors (Fig. 2) had a sensitive area 12 × 16 in. The alpha-sensitive phosphor was silver-activated zinc sulfide deposited on one side of an $\frac{1}{8}$-in.-thick sheet of transparent Plexiglas. This phosphor was placed, sensitive side out, over the open side of a 13 × 17 × 4 in. radio chassis, and covered with a sheet of semiopaque aluminized Mylar, 0.0002 in. thick.* The inside surfaces of the radio chassis had previously been painted with flat-white show-card paint to improve the light collection efficiency of the photomultiplier. The white paint also diffused the scintillations and made the effective sensitivity of the phosphor surface more uniform.

The aluminized Mylar covering was to prevent exterior light from affecting the alpha phosphor. As the covering was not completely opaque, it was

FIG. 2. ALPHA-SENSITIVE UNIT includes 12 × 16 in. phosphor at base of radio chassis with 5-in. photomultiplier mounted on top. Monitor includes eight such units

* Purchased from Wakefield Industries, Skokie, Ill.

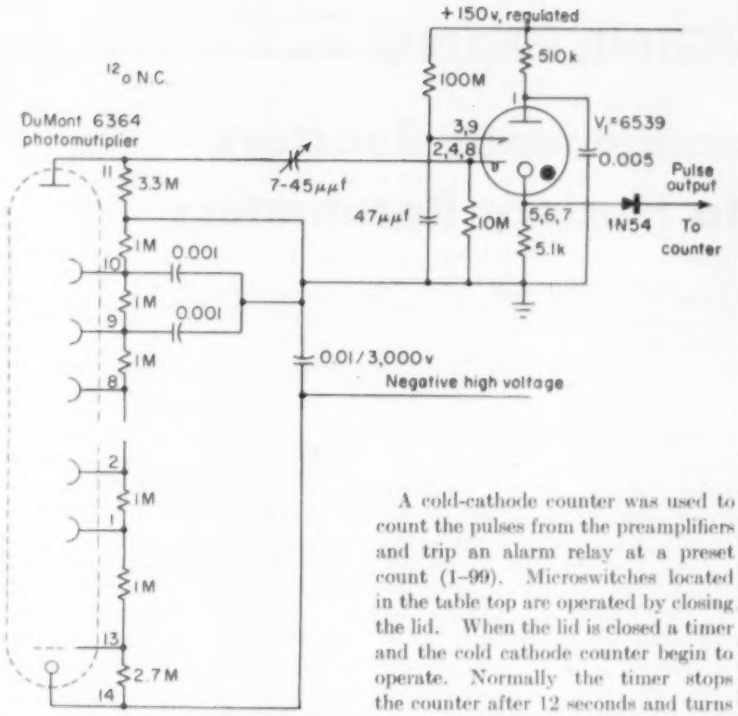

FIG. 3. ALPHA UNIT PREAMPLIFIER is unusual in its use of cold cathode tube, 6539, as preamplifier

necessary to provide the detector table with a lid to seal the garment recess from exterior light during the actual counting operation.

A 5-in. photomultiplier (DuMont 6364) was mounted on the back of the radio chassis by means of a barrel and cone support. The photomultiplier viewed scintillations of the alpha-sensitive phosphor through a hole cut in the radio chassis.

The electrical pulses from the photomultiplier were fed to a 6539* cold cathode tube preamplifier (Fig. 3) located in the probe behind the photomultiplier. A diode adder was used in the output of each preamplifier to transfer the pulses from the 6539 tubes in the eight preamplifiers to a common signal bus. The pulses at the signal bus triggered a cold-cathode counter circuit located in the control unit.

Control Unit

Since the monitor was designed for use by unskilled operators, all control circuits and signal lights were grouped in a relay rack placed behind the detector table.

A cold-cathode counter was used to count the pulses from the preamplifiers and trip an alarm relay at a preset count (1–99). Microswitches located in the table top are operated by closing the lid. When the lid is closed a timer and the cold cathode counter begin to operate. Normally the timer stops the counter after 12 seconds and turns on an "OK" light, indicating a clean garment. If the alarm relay is tripped during the 12 seconds, the timer and counter are halted immediately, and a "Reject" light is turned on, indicating a contaminated garment.

The high voltage supply consisted of an Atomic Instrument Co., model 312 high-voltage supply, a divider network and a high-voltage relay. The divider network permits the high voltage to each of the eight alpha units to be varied independently to compensate for gain differences between photomultipliers.

A high-voltage relay is used to break the high voltage to the alpha heads when the lid is open. This relay is necessary to prevent shifts in the gain of the photomultipliers from exterior light shining through the "Mylar" covering while the high voltage is applied.

A low-voltage supply was designed to supply three d-c voltages: 150 volts, regulated; 225 volts, regulated; and 500 volts, unregulated. A standard rectifier circuit was used for the supply, and OA3 and OD3 regulator tubes were used to provide the necessary d-c regulation. An isolation transformer was used to provide a-c power for the control circuit.

* * *

The information contained in this paper was developed during the course of work under Contract AT(07-2)-1 with the Atomic Energy Commission, whose permission to publish is gratefully acknowledged.

* Cold cathode trigger tube, sold by Rogers Majestic Electronics Ltd., Toronto, Canada.

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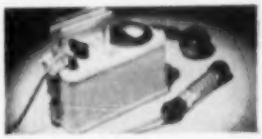

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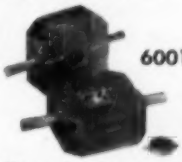

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NUCLEAR ENGINEERING

Fuel Costs in Homogeneous Reactors are Insensitive to Nuclear Parameters

By MELVIN TOBIAS and H. C. CLAIBORNE
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Oak Ridge National Laboratory
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Based on an economic survey, it is concluded that, at the inventory rates and material charges used in the study, nuclear calculations play a relatively minor role in determining the net cost of power from spherical, aqueous homogeneous power-breeder reactors. Thus, attempts to achieve high accuracy in the nuclear portion of general economic survey calculations are often of limited usefulness for aqueous homogeneous reactors and may be so for other reactor types.

Importance

In economic surveys of reactor types and systems, an essential part of the procedure is a nuclear calculation used to determine critical mass and breeding (or conversion) ratios. These data are used in turn to calculate inventory charges, fuel feed costs, and income from the sale of bred material, if any. In analyses of new reactor types, the question arises as to how much the final cost of power will be affected by errors in the nuclear calculations caused by inadequacies in the theory or the nuclear constants. Our experience in studies of aqueous homogeneous reactors leads us to conclude that final power costs, if they are near competitive levels of 4-7 mills/kwh, depend little on the nuclear calculation. Indeed, large errors may be made without producing a corresponding deviation in the end result of the cost estimates.

Such a result is not unexpected since it is a commonly held belief that, out of an estimated cost of 7 mills/kwh for power from a nuclear reactor, perhaps 5 mills are due to capital and other fixed charges that are very little affected by the reactor arrangement chosen. The remaining 2-mills cost is a rather strong function of the physics of the system, but even a 100% change here affects the total cost by only 30%. To test the strength with which errors resulting from the nuclear calculations are communicated to the final answer, a study of the effect of substantial changes (±50%) in nuclear constants was made for a typical case. This

TABLE 1—How Nuclear Parameters Affect Costs for a Specific Two-Region Aqueous Homogeneous Breeder

Heat power (Mw)		*Fuel breeding ratio (atoms made/atoms burned)*	*Concentration (gms/kg D_2O)*		*Reprocessing cycle time (days)*		*Inventory charge (mills/kwh)*		*Cost (mills/kwh)*					
$P_{blanket}$	P_{core}		G_F* (U^{233} + U^{235})	G_U (all U)	T_{core}	$T_{blanket}$	I_{fuel}	I_{Dp}	C_{total}	$C_{invest.}$†	$C_{reproc.}$	C_{op}	C_{fuel}	C_{credit}‡
Standard case														
89	392	1.10	2.79	8.41	337	130	0.42	0.34	6.08	3.74	1.06	0.75	0.19	0.42
Extrapolation distance														
89	392	1.11/1.10§	2.79	8.41	337	129/130	0.42	0.34	6.08/6.12	3.74	1.07	0.75	0.19	0.43/0.39
Blanket fast-diffusion constant														
86/95	395/386	1.10	3.00/2.44	8.99/7.46	363/294	127/135	0.44/0.41	0.34	6.11/6.09	3.74	1.07/1.06	0.75	0.19	0.42/0.40
Core fast-diffusion constant														
93/84	388/397	1.10/1.11	2.57/3.19	7.81/9.51	310/386	133/125	0.41/0.44	0.34	6.08/6.10	3.74	1.06/1.07	0.75	0.19	0.41/0.43
Blanket age														
89/88	392/393	1.08/1.13	2.70/2.94	8.18/8.79	326/354	133/126	0.41/0.43	0.34	6.18/5.99	3.74	1.06/1.07	0.75	0.19	0.31/0.53
Core age														
83/97	398/384	1.11/1.10	2.95/2.17	8.90/6.67	438/262	124/136	0.46/0.39	0.34	6.11/6.07	3.74	1.07/1.06	0.75	0.19	0.44/0.40
Blanket slow-diffusion constant														
89	392	1.10	2.95/2.50	8.90/7.52	357/301	130/129	0.43/0.41	0.34	6.11/6.08	3.74	1.06	0.75	0.19	0.40/0.41
Core slow-diffusion constant														
89	392	1.11/1.09	3.59/1.69	10.8/5.1	434/203	128/131	0.46/0.37	0.34	6.12/6.08	3.74	1.07	0.75	0.19	0.43/0.38
Protactinium absorption cross section														
87/91	394/390	1.09/1.12	2.84/2.74	8.99/7.83	343/330	131/128	0.42	0.34	6.15/6.01	3.74	1.06/1.07	0.75	0.18/0.19	0.34/0.50
Blanket resonance-escape probability														
108/73	373/408	1.08/1.12	2.73/2.85	8.61/8.25	331/343	150/115	0.42/0.43	0.34	6.16/6.04	3.74	1.05/1.09	0.75	0.19/0.18	0.33/0.49
ε for U^{238}														
92/86	389/395	1.14/1.07	2.67/2.92	8.07/8.78	323/352	128/131	0.42/0.43	0.34	5.97/6.21	3.74	1.08/1.06	0.75	0.18	0.54/0.29
Combination case in which ages, diffusion constants, and resonance-escape probability are high; extrapolation distance is low														
83	398	1.13	1.26	3.53	150	121	0.35	0.34	5.94	3.74	1.09	0.75	0.18	0.51
Combination case in which ages, diffusion constants, and resonance-escape probability are low; extrapolation distance is high														
98	383	1.00	4.66	15.4	567	156	0.50	0.34	6.55	3.74	1.04	0.75	0.19	0.01

*Critical concentration. †Investment cost, reactor and turbogenerator. ‡For excess-fuel production. §Result for values used: high/low.

TABLE 2—Properties of the System Investigated

Temperature	280° C
Blanket concentration (gms U^{233}/kg Th)	3
Blanket Th concentration (gms Th as ThO_2/liter)	1,000
Poison fraction in core, ($\Sigma_{a_{poison}}/\Sigma_f$)	0.06
Reactor power (Mw)	
Heat	481
Electricity	125
Plant factor	0.8
Core diameter (ft)	5
Blanket thickness (ft)	2
External power densities (kw/liter)	
Core system	20
Blanket system	14

served as a partial check on the results of a general survey to be described next.

General Survey

The general survey covered the effects of geometrical and some operational variables on the economics and characteristics of one- and two-region, spherical, thorium breeder reactors (*1*). How power cost is affected by core radius, blanket thickness, blanket uranium and thorium concentrations, reprocessing-cycle times, fission-product poisons, and external power density (piping and heat exchangers) was investigated using a consistent method of calculation with a standardized set of nuclear constants and cost factors. All results were for a three-reactor power station delivering 375 Mw of electricity to a power grid.

The reactors studied were moderated with heavy water and had large dimensions from a nuclear standpoint (4–7-ft-diameter cores, 1.5–3.5-ft-thick blankets for two-region reactors; 10–16-ft diameters for one-region reactors). For such reactors, the two-group-diffusion method should provide an adequate estimate of the critical mass (*2*). However, the breeding ratio is more sensitive to inadequacies in the method.

It is important to note that the cost estimates represent only what may be attainable after a successful research and development program. Nevertheless, a study such as this, based as it is upon stated cost factors and a consistent method of calculation, can be used to determine what is, and what is not, of relative economic importance and further provides a rational basis for the selection of most design criteria.

Effect of Variations

Table 1 lists the results of a study of a reactor system whose main characteristics are given in Table 2. Table 3 lists the upper and lower limits used for the nuclear data varied individually in the calculations, together with the standard values employed. All were varied by $\pm 50\%$ with the exception of η of U^{233}, which was given a range equal to the limit of error known at the time the calculations were made.

Table 1 shows the results of the calculations (to obtain fuel costs, $C_{invest.} + C_{op.}$ is subtracted from C_{total}). All but two of the results are based on changes in one parameter only; the two exceptions were cases where a combination of parameters was changed to indicate the effect of extremely unfortunate selection of data. Somewhat more unlucky choices appear possible, but time was not available to examine all variations.

The changes in the final power costs are relatively small and are due principally to altering the amount of credit received for excess fuel production. The largest change is the nearly 0.6-mill/kwh difference between the two extreme cases. Where only individual

TABLE 3—Ranges Assumed for the Nuclear Data

Parameter	*Values*		
	Standard	*High*	*Low*
Extrapolation distance (cm)	15	23	8
$\eta_{U^{233}}$	2.32	2.36	2.28
$\sigma_{aPa^{233}}$ (barns)	97	145	48
Blanket age (cm^2)	212	319	106
Core age (cm^2)	218	327	109
Blanket fast-diffusion constant (cm)	1.49	2.24	0.74
Blanket slow-diffusion constant (cm)	1.17	1.76	0.59
Core fast-diffusion constant (cm)	1.67	2.50	0.84
Core slow-diffusion constant (cm)	1.23	1.85	0.62
Blanket resonance-escape probability	0.56	0.84	0.28

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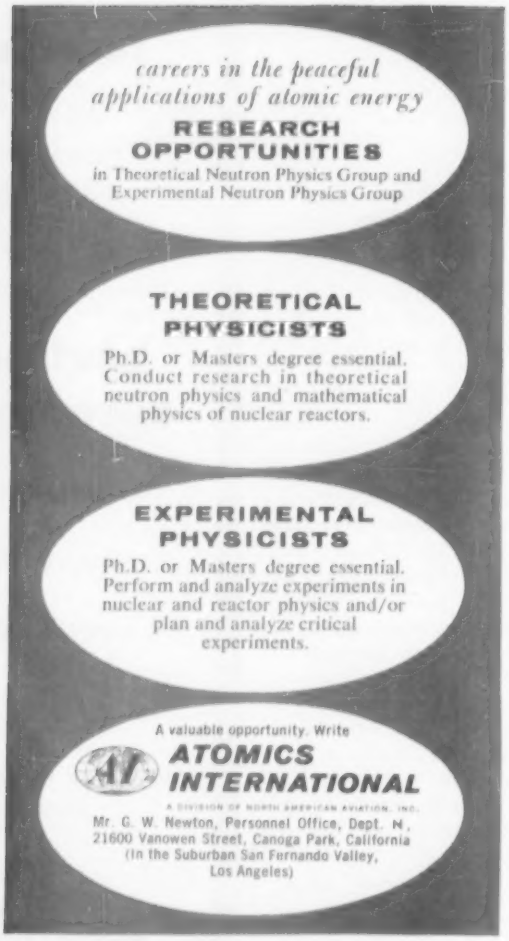
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constants are altered, the net cost differs by less than 0.13 mill/kwh from the standard case.

The core concentration of uranium and the breeding ratio vary considerably. But changes in the former do not lead to proportionally large variations in fuel inventory charges since these charges contain contributions of similar magnitude from the blanket system. Thus, for two cases where the uranium concentrations differ by a factor of 4, the fuel inventory charges differed by only a factor of 1.4. But changes in breeding gain are almost directly converted into changes in credit received for excess fuel production.

Most Significant Changes

The most important cost increases are those produced by increases in the blanket age, the protoactinium absorption cross section, the blanket resonance-escape probability, and decreases in η for U^{233}. Increasing the blanket age produces a rise in fast leakage at the expense of resonance capture in thorium, while all other neutron losses remain practically unaffected. Raising the Pa^{233} cross section causes protoactinium absorption to rise at the expense of thorium capture, as well as a change in *core* isotope ratios leading to higher capture rates in U^{234}, U^{235} and U^{236}.* An increase in resonance-escape probability raises blanket power, increases leakage, depresses resonance capture, and increases thermal capture. A decrease in both resonance and thermal capture in thorium is the principal result of a fall in η of 0.04 (1.7%).

The critical concentration is affected most strongly by varying the ages, the diffusion constants, and, naturally, η.† A 50% rise in the core diffusion constant produced a critical concentration increase of about 28%, while the 1.7% rise in η causes a 4.4% decrease in concentration. The breeding ratio is not affected significantly by changing either the age or the slow-diffusion constant for the core.

None of the quantities investigated significantly affects blanket processing rates except the blanket resonance-escape probability, for which a decrease of 50% leads to a 12% decrease in cycle

* The fuel feed to the core is obtained from the blanket system.

† There are certain obvious nuclear parameters to which the final results may be quite sensitive and which must be known with reasonable accuracy. For instance, in one-region reactors, resonance-escape probability plays an important role similar to that of η in determining critical concentrations and breeding ratios.

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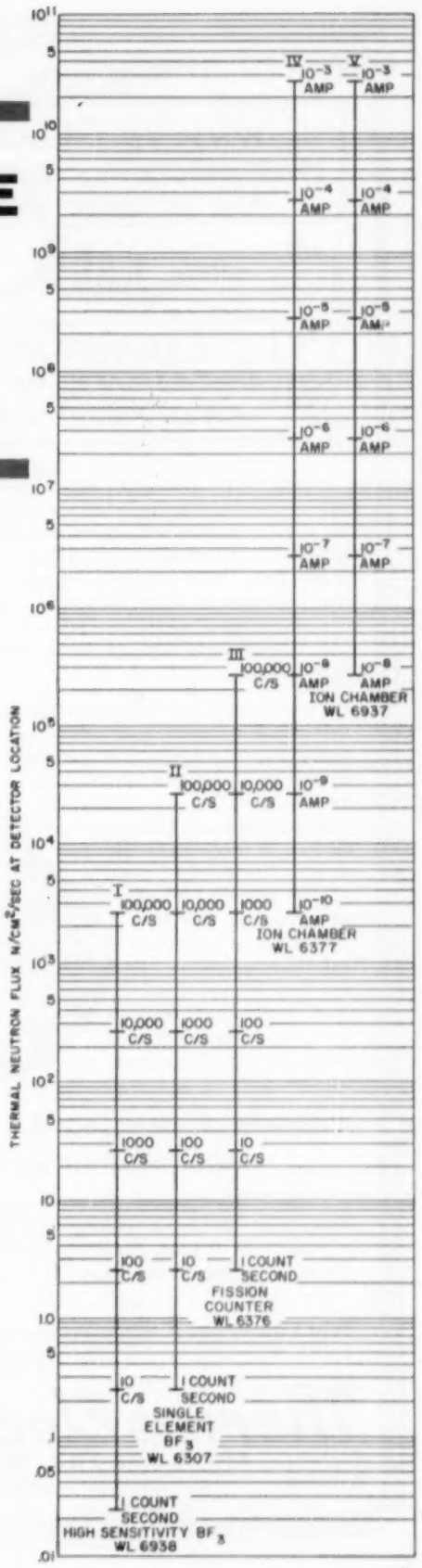

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time. The core reprocessing cycle is affected mainly by the diffusion constants and the core age; the greatest effect observed, produced by lowering the core slow-diffusion constant, is a decrease of cycle time by about 134 days out of 337. However, no significant changes are noted in either core or blanket reprocessing costs.

Fuel, D_2O Costs

In the work reported here, a 12% inventory charge is assessed against fissionable material and heavy water. All fissionable material is valued at $20/gm and heavy water is valued at $28/lb (*3, 4*). Naturally, the question arises as to validity of the results in case of different inventory charges and material costs. Inspection of Table 3 shows that the fuel inventory charge usually is almost compensated by the breeding credit; thus, the net unit cost of power is nearly independent of the value of uranium.

One-Region Th Breeder

A few additional calculations (not tabulated here) using large parameter changes also were made for the case of a 12-ft one-region, thorium breeder reactor. There is a somewhat higher sensitivity to individual parameter changes, since such changes affect the *entire* reactor rather than an individual portion as in the two-region case. The largest deviation between results is a difference of 1.6 mills/kwh between two combination cases where p differs by 20% and the ages, diffusion constants, and extrapolation distances vary by ±50% from the standard values. Individual changes produce much smaller effects.

Conclusions

For the aqueous homogeneous thorium breeder reactors studied, about 80% of the total cost originates in factors independent, or virtually so, of the results of nuclear calculations. Errors in the nuclear calculations were suspected of being of secondary economic importance, and the parameter study made on a typical case justifies this expectation. In these circumstances, efforts to achieve substantial savings should be devoted primarily to such factors as capital costs and thermodynamic efficiency, factors which have more to do with the engineering rather than the nuclear aspects of the reactor.

The conclusion should not be drawn that a simplified treatment of the nuclear portion of an economic survey is permissible under all conditions. For

instance, for a one-region homogeneous reactor, calculations show that an error of about 25% in the value for resonance-escape probability could lead to a gross mistake in the estimate of critical mass, and thus of the fuel inventory charge. Similar examples exist for other reactor types.

In making an economic survey, it is profitable to examine beforehand just how much effort must be expended in the nuclear calculations to obtain a reasonably reliable result. Often only minor and questionable cost differences result from attempts to increase breeding gain or reduce critical concentrations; then practical feasibility is the overriding consideration in choosing the best reactor. Given a particular reactor design, it is obvious that the best techniques of physics ought to be devoted to learning precisely what this design will do, but given only the reactor type, only the simplest reasonable technique may be needed to locate the optimum configuration.

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Decay-Heat Cooling Requirements of Spent Fuel from EBR-2

By C. H. SCHEIBELHUT

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Lemont, Illinois

Fuel elements will be removed from the EBR-2 reactor after they have served for three months and have achieved 2% burnup. After being removed from the core, they will be stored for 15 days in the reactor sodium so that the initially intense heat from fission-product decay can be removed. Then the fuel subassembly will be transferred from the sodium to a disassembly cell where the irradiated fuel will be removed so that it can be reprocessed pyrometallurgically.

As shown in Fig. 1, after removing the subassembly from the sodium, the fuel still generates about 2 kw of decay heat; hence cooling is needed to prevent damage that would complicate recovery of the fuel from the subassembly. Tests described here show that the best way to provide this cooling is by forced convection of argon, which is the atmosphere in the disassembly cell.

Since the fuel assemblies usually are quite complex in shape, it is nearly impossible to calculate decay cooling under natural-convection conditions. Thus a simple experiment usually is necessary.

Experimental setup. A full-size

FIG. 1. How decay-heat generation per spent EBR-2 subassembly drops off with time after removal from core

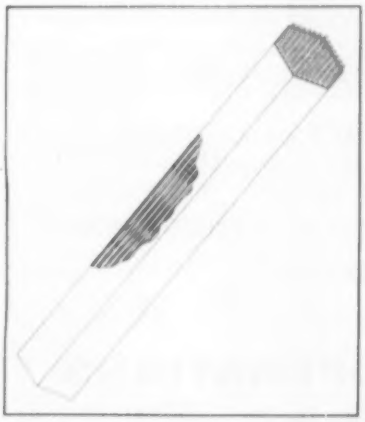

FIG. 2. For experiment, fuel section of EBR-2 subassembly had electrical heaters instead of uranium in cluster of 91 pin-type fuel elements clustered in hexagonal tube of about 2.2 in. across flats. Fabrication of the 18-in.-long pins has been described previously (NU, Aug. '56, p. 44)

Radiation Dosimetry

Edited by Gerald J. Hine and Gordon L. Brownell

1956, 932 pp., 306 figs., 114 tables, $22.00

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Fundamental Principles of Dosimetry

F. W. Spiers, Radiation Units and Theory of Ionization Dosimetry
H. E. Johns and J. S. Laughlin, Interaction of Radiation with Matter
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model subassembly was constructed with electrical heaters substituted for the fuel in the normally fuel-bearing portion of the unit. The model otherwise was identical to the fuel-bearing portion of the subassembly as shown in Fig. 2. For the model, a ceramic-insulated nichrome resistance wire was inserted 14¼ in. (the length of the fuel) into a fuel tube to which one end closure and a spiral rib were welded. Groups of 18 tubes were wired in series and constituted a single circuit. There were five such circuits, each controlled by an autotransformer and monitored by an ammeter and a voltmeter. This arrangement left one tube that was con-

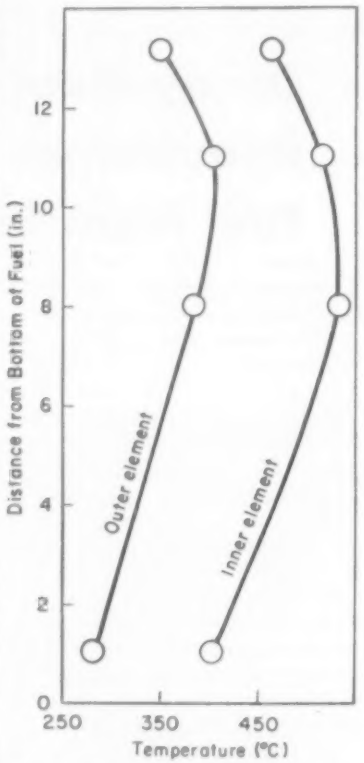

FIG. 3. Temperature distribution along length of pins when power was 261 watts and cooling was by natural flow of air

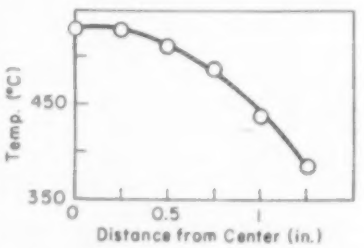

FIG. 4. Temperature distribution across subassembly 1 in. above center when power was 261 watts and cooling was by natural flow of air

trolled separately. A total of 21 thermocouples were welded to various tubes so that vertical and transverse temperature surveys of the tube surface temperatures could be made during operation. The 91 elements were inserted in a reference hexagonal subassembly tube and mounted in a vertical position. Since we desired to test forced-convection cooling as well as natural convection, provision was made so that a blast of cooling air or argon gas could be metered into the bottom of the assembly.

Cooling the subassembly. As is shown in Figs. 3 and 4, at a power of 261 watts with natural convection of air the hottest element reached a temperature of 530° C. Then air at the rate of 9.41 scfm (cubic feet per minute at standard temperature and pressure) was introduced into the bottom of the assembly and the power adjusted to 2,330 watts. Under these conditions, a fuel-tube-surface maximum temperature reached 563° C; air outlet temperature was 444° C. A heat balance indi-

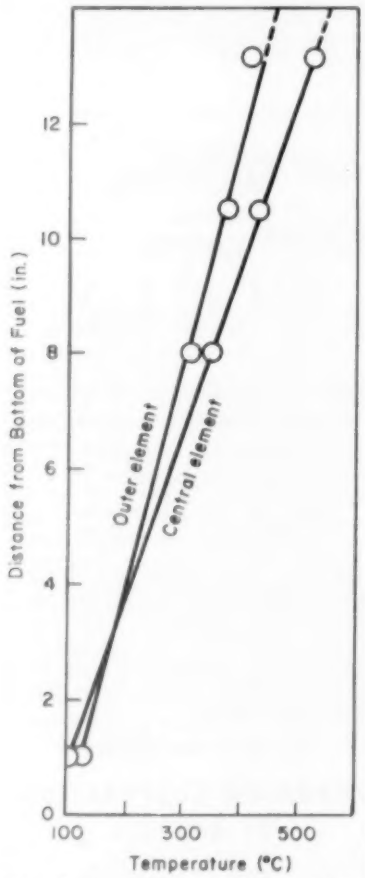

FIG. 5. Temperature distribution along length of pins when power was 2,265 watts and cooling was by forced flow of 12.2 scfm of argon

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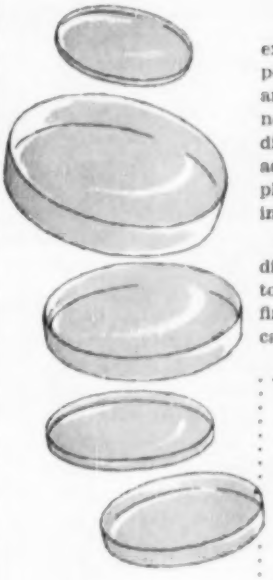

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cates that the air was removing 90% of the heat.

The experiment was repeated using 12.2 scfm of argon gas and a power input of 2,265 watts. As shown in Figs. 5 and 6, fuel-tube-surface maximum temperature reached 536° C, with argon outlet at 453° C. A heat balance indicates the argon was removing 96.5% of the heat.

Cooling the clustered pins. Disassembly of the fuel subassembly consists of removing the hexagonal tube, then removing the individual fuel elements. During these operations (and all preceding transfer operations) cooling gas must be circulated through the subassembly. To remove the hexagonal tube, it is cut at one end by a modified tube cutter and then is pulled from the subassembly. As shown in Fig. 7, the fuel elements still are held in a hexagonal array by the end-grid structure to which each element is attached.

After the hexagonal tube is removed from the pin cluster, axial cooling is no longer possible; crossflow through the cluster is necessary. To determine the cooling requirements for this configuration, the 91 electrically heated fuel tubes were removed from the hexagonal

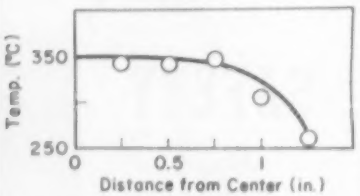

FIG. 6. Temperature distribution across subassembly center when power was 2,265 watts and cooling was by forced flow of 12.2 scfm of argon

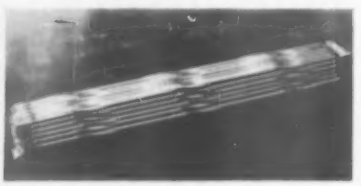

FIG. 7. Fuel-pin cluster after hexagonal tube is removed

can and the cluster was supported horizontally in air. With no forced cooling, the hottest tube reached 570° C with a power input of 490 watts.

Next, the 91-tube bundle was supported in a perforated half-hexagonal tube to which was attached a manifold so that cooling air could be forced into the bottom and sides of the bundle. With 2,200 watts heat input and air

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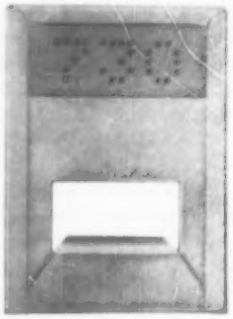

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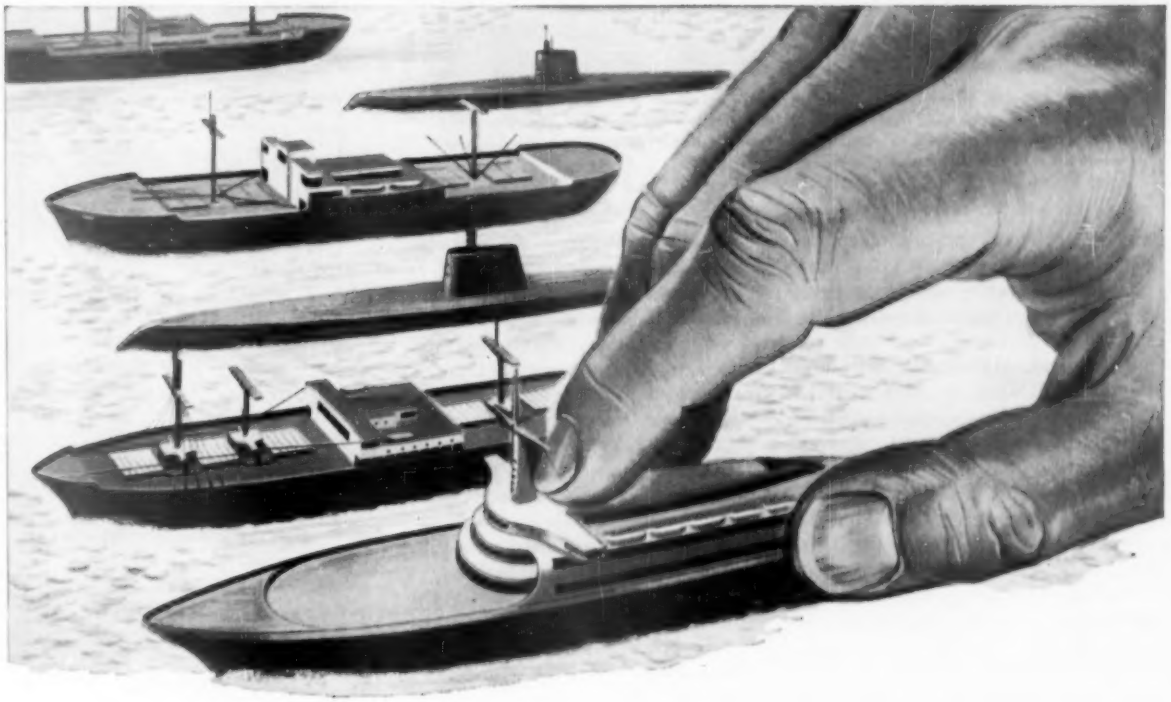

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FIG. 8. Full-size subassembly model (bottom), complete with simulated fuel pins, upper and lower blanket rods, hexagonal tube, top attachment, lower orifice, and bottom plenum, was used to obtain pressure-drop data. Also shown (top) is subassembly with blanket and fuel pins

flow of 9.62 scfm, a fuel-tube maximum temperature reached 645° C. To maintain this temperature while using argon as the coolant, calculations indicate that 13.4 scfm are required while the individual pins are being removed from the cluster. When the pins are kept separate, no further cooling is necessary.

Pressure drop. To obtain data on pressure drop vs. air volume, a full-scale subassembly model was used; it is shown in Fig. 8. From these data, the pressure drop with argon gas was calculated to be as shown in Fig. 9.

Failure of forced cooling. It is important to know how long it would take before dangerously high temperatures would be attained if the source of forced convection should fail. In ascending order of severity, these temperatures are: (a) the iron-uranium eutectic melting point, 725° C; (b) the boiling point of sodium, 881° C; and (c) the fuel-alloy melting point, about 1,200° C.

To determine the time it would take an irradiated subassembly to reach a given temperature, it is necessary to know the natural-convection heat loss as a function of the maximum temperature in the subassembly. Figure 10 shows this relationship as derived from experimental data and an empirical relationship. At any given temperature, the amount of heat generated minus the heat loss is the driving force available to raise the temperature. The heat capacity of the subassembly can be considered the resistance. By assuming constant heat capacity and driving force over 25° F increments, the time necessary for the temperature to rise 25° F can be calculated.

A summation of the times for the various increments over the range gives the time available after loss of cooling before a dangerously high temperature is reached. For a subassembly out of the reactor for more than 15 days, about 5 min will elapse before 725° C is reached; about 7.5 min before 881° C is reached; and about 16 min before 1,200° C.

Conclusion. Positive cooling of the irradiated subassemblies is very important from the time they leave the reactor sodium until they are completely disassembled if damage from overheating is to be avoided.

* * *

The author thanks F. J. Tebo of Argonne National Laboratory for his assistance with these experiments.

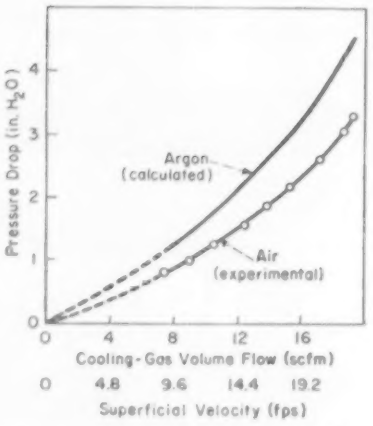

FIG. 9. How pressure drop varies with flow of air and argon

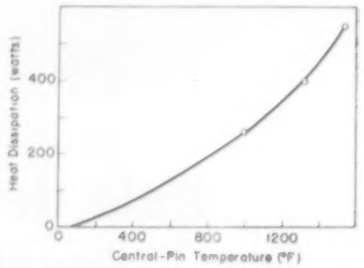

FIG. 10. Variation of heat loss to natural-convection argon as function of maximum temperature of subassembly

A Series for the *F*-Functions of Shielding Computations

By F. T. BINFORD
Operations Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Formation of the integral of the point-source kernel to obtain an expression for the radiation field arising due to a finite shielded source of radiation often gives rise to the so-called "*F*-functions." These *F*-functions often give difficulty because they are not integrable in closed form and are not extensively tabulated. However, it is possible to represent them in the series form that is derived here. The series involves the exponential integral, values of which have been tabulated (*1*).

The *F*-function of order n is

$$F_n(x) \equiv \int_0^{\pi/2} e^{-x \sec\theta} \sin\theta \cos^{n-1}\theta \, d\theta$$

By using the transformation $z \cos\theta = x$, this can be put in the form

$$F_n(x) = x^n \int_x^\infty \frac{e^{-z}}{z^{n+1}} dz \qquad (1)$$

Consider now the integral corresponding to the nth order *F*-function

$$I_n(x) \equiv \int_x^\infty \frac{e^{-z}}{z^{n+1}} dz$$

The zero-order integral is merely the exponential integral

$$I_0(x) = \int_x^\infty \frac{e^{-z}}{z} dz \equiv -Ei(-x)$$

Tables of the higher-order integrals are not available, although Gold has tabulated values of F_0, F_1, and F_2, using a slightly different notation (*2*).

If I_n is integrated once by parts, the result is

$$I_n(x) = \frac{1}{n}\left(\frac{e^{-x}}{x^n} - \int_x^\infty \frac{e^{-z}}{z^n} dz\right)$$

$$= \frac{1}{n}\left[\frac{e^{-x}}{x^n} - I_{n-1}(x)\right] \qquad (2)$$

Successive application of Eq. 2 yields

$$I_0(x) = -Ei(-x)$$

$$I_1(x) = \frac{e^{-x}}{x} - I_0(x)$$

$$I_2(x) = \frac{e^{-x}}{x}\left(\frac{1}{2x} - \frac{1}{2}\right) + \frac{1}{2} I_0(x)$$

$$I_3(x) = \frac{e^{-x}}{x}\left(\frac{1}{3x^2} - \frac{1}{2\cdot 3x} + \frac{1}{2\cdot 3}\right) - \frac{1}{2\cdot 3} I_0(x)$$

$$I_4(x) = \frac{e^{-x}}{x}\left(\frac{1}{4x^3} - \frac{1}{3\cdot 4x^2} + \frac{1}{2\cdot 3\cdot 4x} - \frac{1}{2\cdot 3\cdot 4}\right) + \frac{1}{2\cdot 3\cdot 4} I_0(x)$$

. . .

$$I_n(x) = \frac{e^{-x}}{xn!} \sum_{j=1}^{j=n} \frac{(n-j)!}{x^{n-j}} (-1)^{j+1} + \frac{(-1)^n}{n!} I_0(x)$$

$$n = 1, 2, 3, \ldots . \quad (3)$$

Proof of Eq. 3 follows easily by induction. From Eq. 2 we have

$$I_{n+1}(x) = \frac{1}{n+1}\left[\frac{e^{-x}}{x^{n+1}} - I_n(x)\right] \quad (4)$$

Then, using Eq. 3 in Eq. 4 we have

$$I_{n+1}(x) = \frac{1}{n+1}\left[\frac{e^{-x}}{x^{n+1}} + \frac{e^{-x}}{xn!} \sum_{j=1}^{j=n} \frac{(n-j)!}{x^{n-j}} (-1)^j + \frac{(-1)^{n+1}}{n!} I_0(x)\right]$$

Upon introducing the change of index $i = j + 1$ and rearranging, this becomes

$$I_{n+1}(x) = \frac{e^{-x}}{x(n+1)!} \sum_{i=1}^{i=n+1} \frac{(n+1-i)!}{x^{n+1-i}} (-1)^{i+1} + \frac{(-1)^{n+1}}{(n+1)!} I_0(x) \quad (5)$$

But Eq. 5 is just Eq. 3 for the case $n + 1$, and so the proof is complete.

Upon multiplying Eq. 3 through by x^n and recalling that $I_0(x) = -Ei(-x)$, we obtain for the F-function of order n

$$F_0(x) = -Ei(-x)$$

$$F_n(x) = \frac{e^{-x}}{n!} \sum_{j=1}^{j=n} (n-j)! x^{j-1} (-1)^{j+1} + \frac{(-1)^n x^n}{n!} [-Ei(-x)]$$

$$n = 1, 2, 3, \ldots .$$

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2. E. Gold, *Proc. Roy. Soc.* **A82**, 43 (1909)

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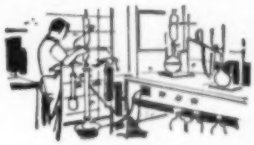

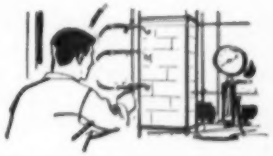

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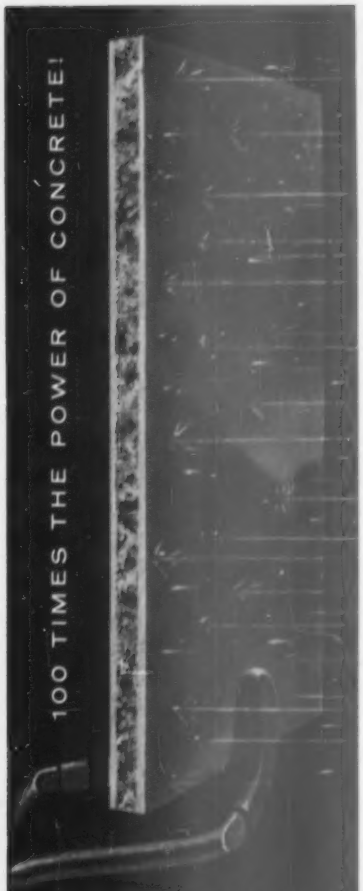

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TECHNICAL ADVANCES

Brookhaven Meeting on Resonance Absorption Resonance absorption was the subject of a two-day meeting at Brookhaven National Laboratory recently. That the last word has not yet been said about this classic sector of reactor theory is attested by the fact that experiments, their analysis, and the underlying theory all came in for vigorous re-examination.

Background. The importance of the quantity p, called the resonance escape probability has been recognized since the earliest days of reactor technology. Briefly, p, is the probability that a fast neutron born in the fission of, say U^{235}, escapes radiative capture in the many resonances in the capture cross section of U^{238} as it slows down to thermal energies. At present, there are 18 known resonances in U^{238} in the energy range 1–500 ev and it is expected that resonances continue to occur, at approximately uniform intervals, with increasing width until they are "washed out" at about 10^4 ev. As neutrons slow down past this energy region, it is necessary to avoid capture in these resonances, which serves only to remove neutrons that could cause thermal fission in U^{235}. Lumping the uranium in the moderator has the effect of separating the neutrons from the uranium while they are being slowed down, so increasing the escape probability.

An early and fundamental, though simplified analysis was given by Professor Wigner. His work gives what might be called the Western recipe for calculating the resonance escape probability. For lumped lattices p can be written as an exponential whose argument is proportional to the "effective resonance integral" of U^{238}. In Wigner's theory this latter quantity may be expressed as the sum of two terms; one of which expresses that part of the capture in U^{238} which occurs at peaks of the resonances and is therefore confined mainly to the surface of the lump, the other of which expresses that part of the capture which takes place at the higher energy, broader resonances or in the wings of the lower resonances and is distributed more uniformly through the volume of the lump. These two components of the resonance integral, apart from their proportionality to mass and surface, depend only upon the cross sections of the fuel atoms and the general character of the slowing-down process. Thus, when they have been tabulated for a particular fuel, calculation of p for a variety of reactor systems is made possible. Two major goals for experimental physicists present themselves then—the determination of the surface and volume terms, and the direct measurements of p in a reactor lattice—and these are reflected in the following sampling of papers given at the conference.

Measurements. W. E. Niemuth of Hanford showed measurements of p in Hanford-type lattices (natural U, graphite moderated). Similar measurements in slightly-enriched U, light-water-moderated lattices were reported by D. Klein of Westinghouse, and C. G. Campbell of Harwell. Although the techniques are at hand, there is still some question (and this stimulated considerable discussion) as to the interpretation of measurements such as these: in particular, absorption in the resonance region may also take place in U^{235}; here a neutron can cause fission, however, and is thus not necessarily lost to the chain reaction.

Analyses. H. J. Kouts (BNL) presented an analysis of all available measurements of this type in this country and abroad which indicated (working backwards from p to the effective resonance integral in U^{238}) that the coefficients of the surface and volume absorption terms obtained in this manner disagree with those obtained by direct measurements in uranium. In particular bulk reactor measurements seem to imply smaller volume and greater surface capture than the direct measurements on uranium. The cause of this discrepancy is not clear at this moment.

B. I. Spinrad of ANL gave a paper touching on these and other problems in the interpretation of these measurements; in his paper was a suggestion for just the type of analysis presented by Kouts an hour later! In addition, R. Sher (BNL) presented a paper on the determination of effective resonance integrals from exponential assemblies.

Theories. Papers treating the theoretical and calculational side of the problem of resonance escape emphasized the increasing concern of physicists for the validity of the simple formulas. Attempts to refine the calculations of resonance integrals, using, in some cases the rigorous transport theory as a starting point have been made recently by N. Corngold (BNL), H. Neumann (Hanford), S. Stein (WAPD) and G. Stuart (Hanford). J. Chernick and K. Spinney of BNL reported on recent work aimed at setting quantitative limits on the ac-

curacy of conventional calculations and at formulating the theory in terms of geometrical "escape probabilities."

Monte Carlo methods. A number of papers and much discussion dealt with a new analytical tool for reactor theorists, the "Monte Carlo" technique used in conjunction with high-speed computing machines. R. D. Richtmyer (NYU) and S. Stein (WAPD) have applied the technique to the determination of p in slightly-enriched-uranium–light-water lattices. D. St. John (Savannah River) and J. Sampson (KAPL) have studied heavy-water-moderated systems and graphite lattices, respectively. At present, these calculations fall just short of the desired accuracy. With faster computing machines they are quite promising.

Wigner speaks. A highlight of the conference was an invited paper by Prof. Wigner. Reference has already been made to the Wigner formulation of resonance capture in terms of surface and volume absorption. In particular the capture can be expressed in terms of the surface to volume ratio of the lump. For cylindrical rods, then, there is a dependence on r^{-1}, where r is the radius of the cylinder. Russian work has recently appeared in which, starting from a point of view apparently quite different from Wigner's, a similar expression is derived, but with a dependence on $r^{-\frac{1}{2}}$. Wigner showed that in his formulation, a similar dependence (on $r^{-\frac{1}{2}}$ results in the case of very thin rods. For somewhat thicker rods, whose dimensions are those of practical interest, both the Wigner and the Russian expressions fit experimental data reasonably well, although the Wigner theory seems to be based on sounder grounds, since it does not neglect the moderating effects of U. Experiments performed here and the USSR to elucidate these effects seem to give contradictory results.

* * *

We are indebted to R. Sher and Noel Corngold of Brookhaven National Laboratory for this account.

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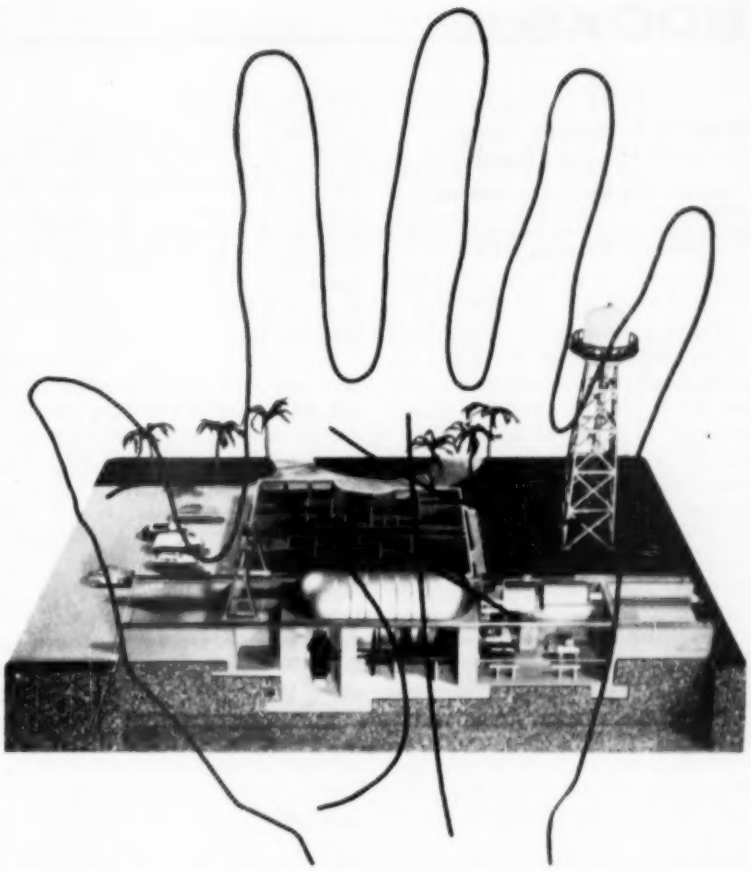

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BOOKS

Progress in Nuclear Energy. Series III: Process Chemistry

Edited by F. R. BRUCE, J. M. FLETCHER, H. H. HYMAN, and J. J. KATZ (Pergamon Press, Ltd., London, and McGraw-Hill Book Co., Inc., New York, 1956, xii + 407 pages, $12.00).

Reviewed by A. F. VOIGT, Ames Laboratory, Iowa State College, Ames, Iowa

This is one volume in a series based on the declassification of much information and the preparation of papers for the Geneva Conference. It is a collection of papers, 36 in number, arranged in eight chapters. Half of these papers are based on material written for the Geneva Conference, while most of the others were written especially for this volume. Very brief prefaces serve to tie together the material in each chapter.

The theme of the volume is expressed in the title, the process chemistry peculiar to the nuclear energy program. Three-fourths of the book is concerned with a more restricted portion of the field, separation processes for removing fission products and fissionable material, Pu^{239} or U^{233}, from the fuel in which they are produced, U or Th. The remainder of the volume deals briefly with chemical processes for recovering U and Th from their ores and for the large-scale preparation of radioisotopes. Some useful appendixes on the radioactivity of the fission products conclude the volume.

Considering the main body of the volume, the papers on separation processes for irradiated fuel, there is first a chapter of five papers on general considerations regarding these processes and the effects of radiation on the chemical systems involved. The next short chapter considers the dissolution of U, Th and some alloys which have been used for fuel elements. This subject is important since the processes currently in use involve nitrate solutions of these metals.

More than a third of the book is devoted to solvent extraction methods. This is not surprising since this type of technology has received more attention than any other and is the type in current use. The subject is treated quite thoroughly, particularly those processes using methyl isobutyl ketone and tributyl phosphate as extractants for the heavy elements.

One paper included in this section is of interest for the picture it gives of the early days of the Manhattan Project. In this paper Thompson and Seaborg describe the discovery of the bismuth phosphate process for the separation and decontamination of plutonium. This was the process which was used successfully at Hanford for years until it was supplanted by the liquid extraction processes.

In contrast to these chapters the next two cover methods which have not yet been carried to plant practice, but are of interest because of inherent simplicity or economy. If enriched fuel is to be returned to gaseous diffusion plants for reenrichment, the desired form is as UF_6. Consequently, methods of separation of uranium which make use of the unique volatility of this material present considerable advantages. One chapter is devoted to processes based on the differences in volatility among the fluorides of U, Pu and the fission products. The next chapter presents processes which have been called pyrometallurgical. If the very high degree of decontamination attainable by aqueous methods is not necessary, simpler methods for reprocessing may be usable which leave the fuel in its metallic state. Such methods, including volatilization, oxide slagging, fused salt and immiscible metal extraction, have received considerable attention in recent years.

This volume is unique and valuable for a number of reasons. A large proportion of the papers are reviews covering types of processing or emphasizing the principles underlying separation methods. While about half of it is based on Geneva Conference papers, which are also available in the various volumes of the proceedings, the papers have been improved by being edited for this volume and in the present form they are much easier to handle than in the mighty tomes of the proceedings. Most of the other papers are not available elsewhere. Many of these are surveys which have been written specifically to tie the volume together and maintain unity. The international character of the volume is another strong argument in its favor. The papers are about equally divided between Great Britain and the U. S., with one contribution from Canada. This volume is also unique in that its subject matter, reactor chemical engineering, has received very little previous publication. Though this fact is undoubtedly due to classification problems, the editors and publishers can be congratulated on getting such a useful volume out so soon after declassification of the material made it possible.

Criticisms are few and probably not important. The large amount of space given to liquid extraction problems, although it may be justified in view of their importance, tends to produce a fairly monotonous series of flow sheets which could be of interest only to a specialist. One of these ubiquitous flow sheets is essentially meaningless since no legend is included by which its many letters and numbers could be interpreted. In contrast to the many pages devoted to liquid extraction, only a cursory treatment is given to the processing of ores and the preparation of U and Th compounds for reduction to metal. However, classification problems may have interfered with the editors' desire to include more on these topics.

In summary, this is a fine piece of work and one which should find considerable use in reactor engineering courses and for general reference and study in the reactor industry.

Radiation Dosimetry

Edited by G. J. HINE and G. L. BROWNELL (Academic Press, Inc., New York, 1956, xiv + 932 pages, $22.00).

Reviewed by L. H. GRAY, Mount Vernon Hospital and the Radium Institute, Northwood, Middlesex, England.

Radiation, a physical agent, and dose, a physicians concept, were married in haste just 60 years ago when the whole medical profession rushed precipitantly to apply the discovery which had captured its imagination. In January 1896 it was to the physics laboratory that the physicians brought their patients for examination. In 1956 there are physics laboratories associated with very many radiotherapy departments, and the "Health Physics" department, as it is commonly called, accounts for an important fraction of the budget of an atomic energy undertaking.

Radiation Dosimetry is a textbook for the specialist and in particular for the physicist working in the field of radiation biology or radiation medicine. The subject is treated comprehensively, both as to theory and practice. Within the 932 pages of Radiation Dosimetry, Hine and Brownell have covered all important aspects of the dosimetry of ionizing radiations. The names of

Spiers (Radiation Units and Theory of Ionization Dosimetry), Johns & Laughlin (Interaction of Radiation with Matter; Calorimetric Methods; X-rays and Teleisotope γ-rays; High-Energy Electron Beams), Boag (Ionization Chambers), Tobias, who with Birge and Anger treats the dosimetry of heavy charged-particle beams, Rossi (Neutrons and Mixed Radiations), to quote at random a few among the more senior authors, are sufficient guarantee of the authenticity which the editors have secured for many of the topics which they have treated. X-ray standardization, however, is an unfortunate exception. Since the "open-air" chambers maintained at the standards laboratories throughout the world are the ultimate reference instruments for all X-ray dosimeters one would expect to find in a textbook of radiation dosimetry a chapter devoted to the theory and practice of this instrument and an appraisal of the attainable accuracy by reference to recent intercomparisons. In the present volume the reader has to piece together the information he needs from three different chapters.

A separate treatment of the roentgen and the open air chamber might have cleared the way for a simpler treatment of the fundamental concepts of the dosimetry of ionizing radiation. Spiers follows the traditional pathway of chronological development. This is no doubt born out of his long experience as a teacher, in which respect he has an advantage over the reviewer, who cannot easily stand either in the position of teacher or taught. He can only record that this chapter made him very conscious of the fact that the pathway has been a tortuous one involving a succession of compromises. The reader has to pass through the tongue-twisting definition of the roentgen; through niceties of wording over which members of the International Units Commission wrangle triennially; the officially extinct rep, the little used energy unit—right in substance, but unhappily named; and the rem, which is a convenient symbol and not a unit at all, before arriving at a general treatment of the relation between ionization and absorbed energy. The tenacious reader is ultimately rewarded by a general treatment which is presented with admirable clarity and includes a good exposition of the refinements in cavity theory recently introduced by Spencer and Attix, and by Burch. Spiers accurately reflects the untidy development of the subject. Having arrived

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after 60 years at a concept (absorbed dose) and a unit of dose (the rad) suited alike to the needs of the physicist and the radiobiologist, recommended as the fundamental unit of absorbed dose by the International Units Commission, and about to be introduced into routine use in radiotherapy departments in Great Britain, should not the exposition of this concept and its realization in practice logically form the point of departure for a textbook of radiation dosimetry?

The standardization of radioactive isotopes is well presented by Sinclair who himself participated in a post-war research program in Great Britain concerned with the precise assay of the β- and γ-ray emitters.

The blackening of a photographic plate and the emission of light by a phosphor were the first properties of matter to be pressed into the service of dosimetry. Both gave way in the face of a demand for an accurate direct reading dosimeter, but the photographic emulsion, by reason of its great sensitivity and exceptionally wide range of dose rate independence has always retained an important place in dosimetry which may be appraised by reference to Dudley's thorough and well documented chapter.

After an eclipse of nearly 50 years, fluorescence dosimetry is undergoing a renaissance, thanks to a series of remarkable technical developments—the photomultiplier, the organic phosphor, large inorganic single crystals and the multichannel pulse height analyzer. This form of dosimetry holds the best promise at the moment of providing much needed information about background levels of radiation in man and his environment. The reader wishing to take advantage of these developments will find just the kind of information which he requires in the chapter on scintillation detectors by Ramm.

Likewise Boag presents with admirable clarity a wealth of information on some of the less well understood aspects of ionization chamber design such as the relation between the electrostatic field and the efficiency of collection at very high dose rates and with pulsed beams.

The chapter on chemical dosimetry by Taplin will introduce many readers to a variety of single-phase and two-phase hydrocarbon-dye systems which the author has himself extensively investigated. Some of the systems give color changes corresponding to a change of 1 *p*H unit after exposure to as little

as 10 r. Such firsthand information is very valuable, but the chapter suffers from a lack of balance. Solutions of diphenyl picric hydrazine in chloroform, which give color changes when exposed to doses as low as the hydrocarbon-dye systems receive no mention, and relative to the dye system little space is devoted to the ferrous system which is more widely used as a reference standard in chemical dosimetry than any other system at the present time.

Clinical applications of dosimetry receive full attention in a chapter by Johns on dose distribution and dosimetric problems which arise in X- and γ-ray teletherapy, and in two chapters on β-ray dose distributions in tissues, which together comprise nearly 200 pages. In the first, Loevinger, Japha and Brownell discuss β- and γ-ray dose distribution around discrete radioactive sources, and in the second Loevinger, Holt and Hine discuss the inhomogeneous dose distributions which arise from the administration of radioactive isotopes. The evaluation of mean β-ray energy from the forms of β-ray spectra originally undertaken by Marinelli, Brinckerhoff and Hine, and Loevinger's valuable original treatments of the dose distribution around isolated β-ray sources situated in an absorbing medium, provide the basic information which is elaborated in these two chapters in a comprehensive manner. Bemis contributes a chapter on survey instruments and the book concludes with one on isotope shipment and disposal by Cowan.

The editors are to be congratulated on the large measure of success with which they have carried through their attempt to present a comprehensive and authentic account of their subject. By the wide dissemination of basic information the book will make its own contribution to the advancement of radiation dosimetry.

BOOKS RECEIVED

Transport Processes in Applied Chemistry, by R. C. L. Bosworth (John Wiley and Sons, Inc., New York, 1956, x + 387 pages, $12.00). Transport processes in this book are concerned with movement of mass (diffusion) or of nonmaterial quantities, e.g., heat and electricity (conduction). From the simple processes, it proceeds to coupled processes, and the "grand transport processes," the latter considering systems involving a series of irreversible processes.

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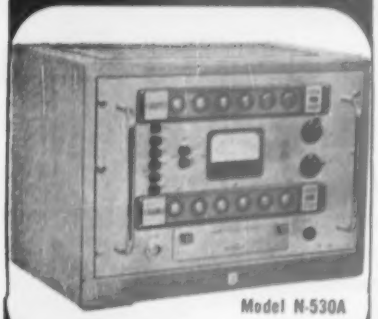

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APPLIED RADIATION

The following tracer methods were among those discussed at Tracerlab's recent Boston symposium on uses of radioactivity in the petroleum industry.

Milker Supplies Ba^{137} Free of Parent Cs^{137}

The advantages of long-lived and short-lived tracers are combined in the gamma milker described by Jerome Kohl of Tracerlab's Western Division. An ion-exchange resin (Dowex-50 type) in a replaceable cartridge holds the 30-yr cesium parent and discharges 2.6-min barium for tracer studies. Parallel cylinder systems draw a carrier fluid (elutriant) into the resin column, discharge it with the barium, and flush the injection line with a small volume of inactive liquid.

Since the daughter reaches equilibrium with its parent in about 10 min, the experimenter can use repeated shots at short intervals. The "leakage" of cesium with the barium is small—rising to 0.03% at the 20th shot when shots are frequent. The barium appears as a water-soluble salt. The injector works into systems with pressures up to 600 psi.

The device can be constructed to supply injections containing from a small fraction of a mc to 5 mc in a few cubic centimeters of elutriant. The standard cesium cartridge has a 5-mc loading. Cartridges are easily replaced sealed units.

The milker has already found several uses. In circulating-fluid systems one can use a pulse injection for flow measurements with confidence that the tracer activity will shortly be negligible. The short-lived barium is useful also for classroom demonstrations of coincidence loss and half-life.

The makers hope to develop other cartridges that will milk Y^{90} from Sr^{90}.

Activation Method For Particle Size

A new use for neutron activation is in particle-size determination. George W. Leddicotte described the method. The particles are activated and then allowed to settle out of a liquid suspension. The rate of change of the count at the counter level with sedimentation indicates particle size.

C^{14} Is Tracer for Gasoline Components

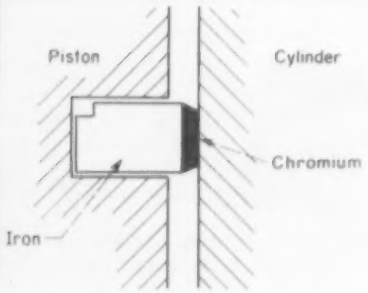
Automotive engineers face problems that arise from unequal distribution of various fuel components among the cylinders of their engines. Douglas E. Cooper of the Ethyl Corporation has developed a successful method for measuring the nonuniformity by labeling a component with C^{14}.

Timed sampling valves withdraw minute volumes of the combustion gases from each cylinder. The gases are bubbled through barium hydroxide in a spiral-path absorber to remove the carbon dioxide. The resulting barium carbonate then goes to a carbon dioxide generator, and the soft betas of the resulting purified carbon dioxide are counted in a sensitive ion chamber with an electrometer.

Two Tracers Find Piston Ring Wear

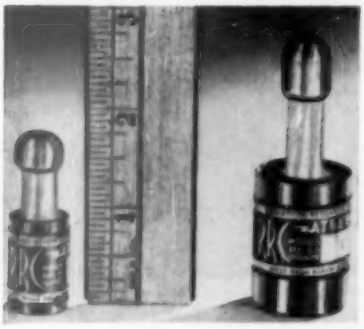
With a chrome-faced piston ring and gamma-ray spectrometry it is possible to make simultaneous studies of ring wear in the piston groove and on the cylinder wall. R. G. Abowd and C. Alsterberg of the Ethyl Corporation described the method at the recent Tracerlab symposium.

In such a ring neutron activation produces 27-day Cr^{51} (0.32-Mev γ) and 45-day Fe^{59} (1.1-, 1.3-Mev γ's). These are counted in the lubricating oil. In the kicksorter, pulses greater than 15 volts represent iron. A window set to accept pulse heights between 10 and 15 volts detects the chromium. This count must be corrected for a large (but accurately determined) background from degraded iron gammas.



Shell Development Co. has used the same two isotopes. They activated a chromium-plated ring and an iron piston wall to study wear differences.

PRODUCTS AND MATERIALS



20-kv Sr^{90} Batteries

Nuclear batteries shown above are of the beta-current type (NU, Nov. '55, p. 129). Betas from Sr^{90}/Y^{90} penetrate polystyrene insulator surrounding the anode and are collected by an aluminum shell. Both batteries operate at 20 kv potential and have 10-$\mu\mu$f capacitance. Model F-10 provides 10 $\mu\mu$amp from 2 mc of Sr^{90}, and F-50 provides 50 $\mu\mu$amp from 10 mc. Thick lead shield reduces radiation to <7.5 mr/hr 1 in. from the surface.—Radiation Research Corp., 140 E. 59th St., N. Y. 22, N. Y.

Gamma Ray Camera

New gamma-ray cameras use 10 curies of Cs^{137} or 20 curies of Ir^{192} and produce a conical beam of radiation 60 deg wide. Model E-39, shown above, is operated by a remote control box; E-37 is opened and closed by controls on camera body.—Tracerlab, Inc., 130 High St., Boston, Mass.

Gamma ray pocket dosimeter. Self-contained personnel monitor for gamma radiation available with full scale of 0.2, 1, 5, 10, 50 or 100 r. Companion charging unit weighs only 3¼ lbs.—Cambridge Instrument Co., Grand Central Terminal, New York 17, N. Y.

Small Photomultiplier

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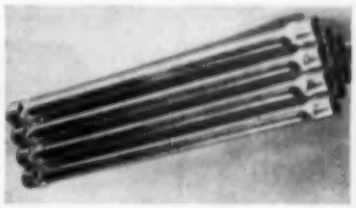

Fuel Elements

Tubular fuel elements (above) permit 50% increase in reactor operating power while maintaining the same film boiling safety factor. Heat transfer surface increases almost 66%. Metal to water ratio decreases almost 52% and more uniform distribution of fuel is accomplished.—Glenn L. Martin Co., Baltimore 3, Md.

RADIATION DETECTORS AND ACCESSORIES

Monitors

Beta or gamma contamination of floors, atmosphere, or personnel can be detected with equipment now available. G-M tubes mounted in a rotatable shield have 24 in. effective length as monitor FM-1, shown here, is pushed along the floor. Reads 0.1–20 mr/hr full scale.

In continuous air monitor, AM-1, air from the atmosphere is pumped past glass-fiber filter paper. Paper travels 1 or 4 ft/hr through a counting shield and onto a takeup reel. Visual or audible alarms register at desired activity level.

Two-second personnel monitoring is possible with portal monitor PM-2A. It houses 7 individual detectors in vertical frame and 4 in base. Has 8 alarm channels.—Eberline Instrument Div., Reynolds Electrical and Engineering Co., P. O. Box 279, Santa Fe, New Mexico.

Plastic scintillator. New plastic phosphor, NE 102, provides light output approaching that of best liquid scintillator compositions with advantage of ready machinability. Available in rough ingot form or machined to specifications, in sizes varying from a micron to a meter.—Nuclear Enterprises Ltd., 1750 Pembina Hwy., Winnipeg 9, Can.

Products Index

Radiation Detectors and Accessories 71
Reactor Components 71
New Materials 72
Literature Available 73
Industry Notes 75

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NEW MATERIALS

Doping Agents

Elements and alloys of periodic chart groups III and V are now available in virtually all shapes and sizes. These high-purity metals can be used as doping agents for germanium and silicon and in *npn* and *pnp* crystals. Minimum thickness 0.0005 in.; minimum diameter 0.0002 in.—Alpha Metals Inc., 56 Water St., Jersey City, N. J.

C^{14} *d*-Sorbitol

Uniformly C^{14}-labeled D-Sorbitol (G) is available at specific activity of 5 mc/millimole in 5 package sizes 0.01–1 mc.—Nuclear-Chicago, 229 W. Erie St., Chicago 10, Ill.

License-Exempt C^{14} Compounds

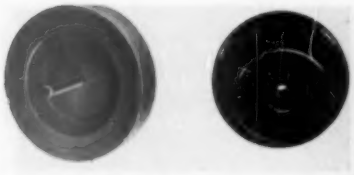
No license is required to purchase the new 50-μc packages of 38 widely used C^{14} compounds. Specific activity is 1 mc/millimole. Presently available compounds include sodium carbonate, bicarbonate and acetate-1-C^{14}.—Volk Radiochemical Co., 5412 N. Clark St., Chicago 40, Ill.

•

Crystals. Specialized natural and synthetic crystals offered for X- and γ-ray diffraction work.—Crystals S. A., Case Mont-Blanc 281, Geneva, Switzerland.

Rare Earths. Wide variety of high-purity rare earth oxides and compounds are now available in the U. S. Imported from England, earths are available in grades up to 99.998% certified purity.—Jarrell-Ash Co., 26 Farwell St., Newtonville 60, Mass.

Columbium and tantalum. Oxides and metals in purities up to 95.5% are now in volume production.—Kenna-metal Inc., Latrobe, Pa.



Leadcast

New shielding material for radioactive materials is a plastic compound containing up to 95% lead. Can be molded with excellent bonding to structural members as in flywheel with steel shaft shown above.—Telectro Industries Corp., 35–18 37th St., Long Island City 1, N. Y.

95%-Enriched N^{15} Compounds

Following compounds labeled with stable N^{15} enriched to 95% (previous maximum 60%) are now commercially available: nitric acid, ammonium nitrate (nitrate labeled), potassium nitrate, ammonium nitrate (ammonium radical as well as ammonium and nitrate labeled), ammonium chloride, nitrogen gas, and potassium phthalimide.—Isomet Corp., P. O. Box 34, Palisades Park, N. J.

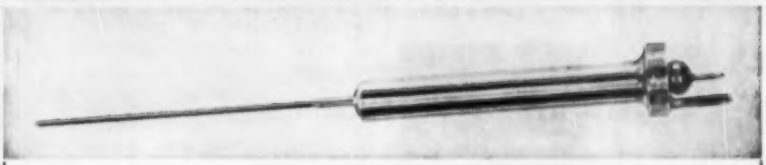
LITERATURE AVAILABLE

Graphite. Bound reprint of paper, "The Production and Properties of Graphite for Reactors," presented at the Geneva Conference by L. M. Currie, V. C. Hamister and H. G. MacPherson. Comprehensive scientific treatment of subject of artificial graphite as construction material for atomic reactors and accessory equipment. 61 p.—National Carbon Co., 30 E. 42nd St., New York 17, N. Y.

Scientific instrumentation. Compilation of probes and ore-surveying instruments—Eberline Division, Reynolds Electrical and Engineering Co., 805 Early St., P.O. Box 279, Santa Fe, N. M.

Computer components. Bulletin MT-104 has data on magnetic cores. Bulletin MP-105 has specifications on magnetic memory planes.—General Ceramics Corp., Keasbey, N. J.

Filter pumps. Bulletin 102 describes centrifugal filter pumps which can remove particles down to 1 micron from highly corrosive solutions.—Sethco Mfg. Co., 70–78 Willoughby St., Brooklyn 1, N. Y.



Lelab metal-walled G-M tubes for anti-coincidence applications—where uniformity counts!

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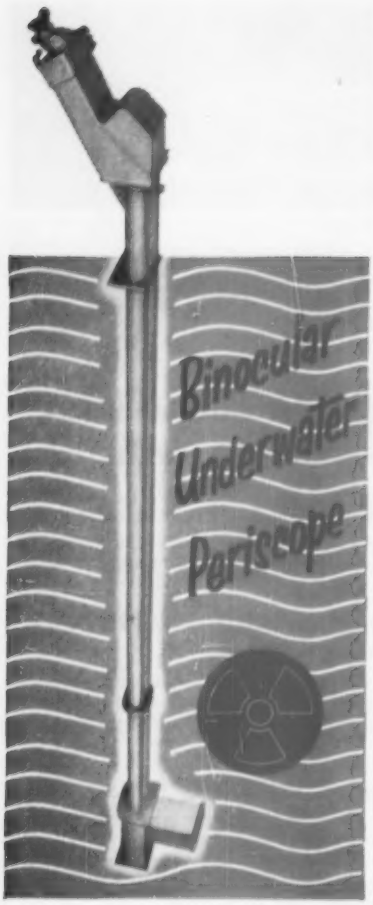

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KOLLMORGEN
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Preamplifier. Folder gives specifications and data on design, operation, and application of vibration pickups and preamplifiers. 4 p.—Brush Electronics Co., 3405 Perkins Ave., Cleveland 14, O.

Frequency counter. Bulletin describes and illustrates a 0–1.1-Mc frequency counter with individual time markers. 4 p.—Hewlett-Packard Co., 275 Page Mill Rd., Palo Alto, Cal.

Microvoltmeters and amplifiers. Two data sheets covering d-c voltmeters from 10 μvolts to 1,000 volts, 100$\mu\mu$a to 100 ma and amplifiers with drift less than ± 2 μvolts.—Kay Lab, 5725 Kearney Villa Rd., San Diego 11, Cal.

Power and gas tubes. Booklet PG101C contains technical data on 175 types of tubes, including power tubes, rectifiers, thyratrons, ignitrons, magnetrons, and vacuum-gage tubes. 24 p.—RCA Tube Div., Harrison, N. J.

Research. Facilities of Allis-Chalmer's central research laboratories are described in digest form in this 24-page bulletin 48B8448.—Allis-Chalmers Mfg. Co., 1316 S. 70th St., Milwaukee, Wis.

Shielding windows. Bulletin PE-51 has charts, graphs, and sketches explaining shielding, transmittance, and radiation-darkening characteristics of glasses having specific gravities of 2.7, 3.3, and 6.2. 12 p.—Corning Glass Works, Corning, N. Y.

Assembly kits. "Murder in the Model Shop" is an unusual 48-page book combining racy detective story with catalog of electromechanical assembly kits and analyzers.—Servo Corporation of America, New Hyde Park, N. Y.

Silicon diodes. Six-page brochure gives specifications and ratings of high-conductance junction types and high-frequency bonded types. Four-page brochure lists rectifiers, transistors, and diodes.—Transitron Electronic Corp., Wakefield, Mass.

Capacitors. Bulletin AE-300 contains information on low-inductance capacitors in the range of 20–125 kv and energy content of 500–8,000 joules.—Axel Bros. Inc., 134–20 Jamaica Ave., Richmond Hill 18, N. Y.

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The NUMAR* Precision Gaussmeter utilizes the principles of nuclear magnetic resonance, by which the nuclei of certain chemical isotopes resonate at specific frequencies when subjected to various magnetic fields. It then becomes possible to determine the strength of any magnet by placing in its field a sealed probe containing known isotopes. The resonant frequency then becomes an exact measure of the magnetic field strength.

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- ***for magnetic field plotting*** of contours and gradients.
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Instrument includes 4 sealed probes, oscillator and power supply. Write for complete specifications and information Bulletin M-212.

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154 Boylston Street, Boston, Mass.

"Canned" pumps. Bulletin 1001 describes design and manufacture of leakless motor + pumps.—Nuclear Pump Inc., 100 E. Price St., Philadelphia 44, Pa.

Gamma radiography. Booklet gives detailed data, descriptions of remote handling equipment for strong gamma sources. 18 p.—Nuclear Systems Div., Budd Co., Philadelphia 32, Pa.

Cobalt bibliography. "Cobalt and Its Alloys, a Summary on Allotropy and Phase Diagrams" is a 100-page loose-leaf bibliography.—Cobalt Information Center, Battelle Institute, Columbus, Ohio.

UO_2 bibliography. Booklet contains approximately 100 references on uranium oxide.—Nuclear Engineering Div., Penn-Texas Corp., 730 Fifth Ave., New York 19, N. Y.

Oscillographs. Company magazine describes oscillographs and galvanometers. 16 p.—Hathaway Instrument Div., Hamilton Watch Co., 1315 S. Clarkson St., Denver, Colo.

Resistors. Brochure on precision wire-wound resistors lists wattage, resistance, and dimensions.—Dmeter Mfg. Co. Inc., 22-24 Larkin Plaza, Yonkers 2, N. Y.

Controller. Bulletin of 56 pages contains data and control principles of pneumatic controller.—Bristol Co., Waterbury 20, Conn.

Electronics. Over 27,000 items are listed in this 356-page catalog—Allied Radio Corp., 100 N. Western Ave., Chicago 80, Ill.

Ratemeter, amplifier. Specification S901-4 describes log-count-rate meter for reactor startup. Range 1–10,000 cps. Specification S901-1 details safety amplifier for reactor control. Both 4 p.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.

INDUSTRY NOTES

▶**Nuclear Instrument and Chemical Corp.** will change its name to Nuclear-Chicago Corp. if stockholders approve.

▶**Instrument Division of Hycon Mfg. Co.** has been awarded an Army contract to develop a gamma-ray densitometer that will step up automation of TNT production.

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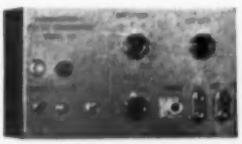

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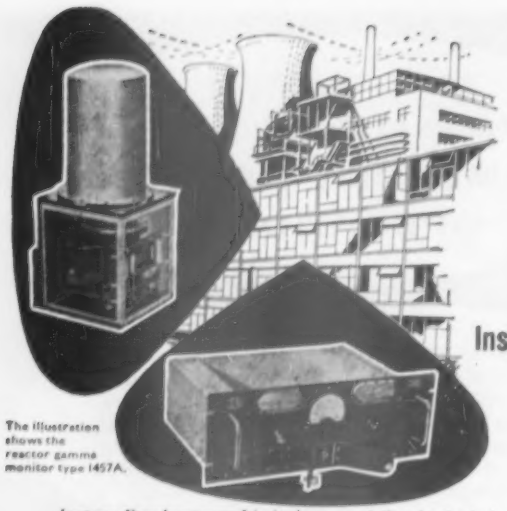

The illustration shows the reactor gamma monitor type 1457A.

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Isotope Developments Limited, as specialists in the industrial and research application of atomic energy, are playing a part in the instrumentation of the Calder Hall Power Reactor.
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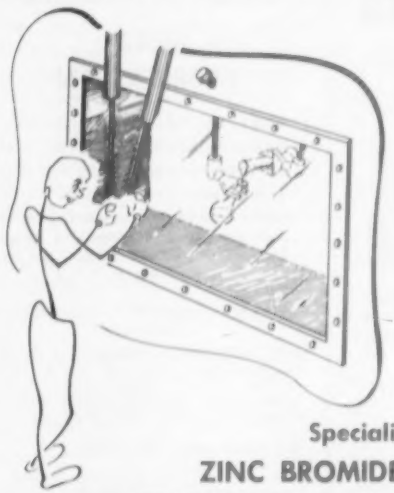
SHIELDING WINDOWS



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* AS DEVELOPED BY ARGONNE NATIONAL LABORATORIES

▶**Corning Glass Works** has announced a 20% increase in the price of its standard line of radiation shielding glasses.

▶**Wertheim and Co.,** investment bankers, have acquired a stock interest in **Gulton Industries Inc.** and have placed two directors on the Gulton board.

▶**Baird Associates-Atomic Instrument Co.** has placed privately $750,000 of 10-year, 5½% subordinated debentures. Proceeds from the issue are being applied to repayment of short-term bank debt and to finance facilities for their Atomic Instrument subsidiary.

▶**Mine Safety Appliances Co.** has formed a wholly-owned subsidiary, MSA Research Corp., to consolidate and expand programs of basic research in chemistry, physics, and nuclear energy.

▶**Electro-Measurements Inc.** has moved into a new 26,000 ft² building at 7524 S.W. Macadam Ave., Portland 1, Ore.

▶**Neutronics Research Co.** at 165 Lake St., Waltham, Mass. has been founded for research-and-development in countermeasures, communications, medical devices, and control circuits.

▶**Servomechanisms Inc.** has opened new corporate offices at 445 Park Ave., New York City.

▶**General Controls Co.** has moved to new facilities at 1330 Hampton Ave., St. Louis 10, Missouri.

▶**General Precision Laboratory Inc.** has begun construction of a 22,000 ft² engineering building scheduled for completion in July, 1957.

▶**Acoustia Associates Inc.** has delivered to the AEC what is said to be the world's most powerful ultrasonic cleaning system.

▶A $6.5 million tantalum-columbium plant will be built by **Fansteel Metallurgical Corp.** in Muskogee, Okla. Tantalum is used in capacitors, columbium in experimental thermal reactors.

▶**Bendix Aviation's Cincinnati Division** will occupy a new plant in suburban Hyde Park that will triple its facilities for manufacturing dosimeters, and nuclear and ultrasonic instruments for industry.

LETTERS

Reactor Produced Nitrogen

DEAR SIR:

Reference is made to our article in the July issue of NUCLEONICS entitled "Producing Chemicals with Reactor Radiation." On page 23 in the diagram, under Fixed Nitrogen, it should read "70,000 tons of Nitrogen as NO_2 is worth . . . . " (not "70,000 tons of NO_2 . . . ") for, as it reads correctly in the paragraph under nitrogen fixation, "Burnup of one mole of U^{235} will fix 70–80 tons of fixed *nitrogen* as nitrogen dioxide." This means that for 70,000 tons of fixed nitrogen as nitrogen dioxide, the value for the nitrogen dioxide produced is 46/14 times larger.

—PAUL HARTECK
Department of Chemistry
Rensselaer Polytechnic Institute
Troy, New York

Radiation Effects—Plastics and Elastomers

DEAR SIR:

I wish to compliment you on the way you handled my article "Damaging Effects of Radiation on Plastics and Elastomers" which appeared in your September issue—particularly in regard to the arrangement of the large table which contained so much information.

More recent work we have done on the effect of dose rate does not agree with the results as presented in the article. Rechecking our dosimetry revealed that the original dose rates were in error. As a result all total doses reported for the spent fuel elements should be multiplied by a factor of 0.6. From the new data we have obtained, at least in the dose rate range of 0.5–100 $\times$ 10^3r/hr, it appears that the dose rate has little if any effect on the damage to properties.

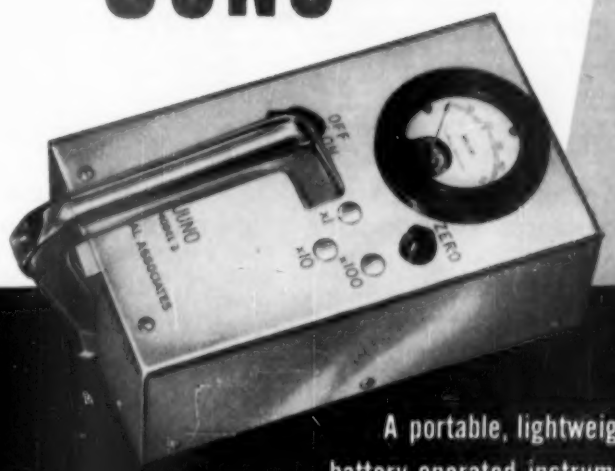
—ROBERT HARRINGTON
Hanford Atomic Products Operation
General Electric Company
Richland, Washington

CORRECTION

In the table of research reactors offered for export (NU, Nov. '56, p. 70) there is an error in the entry for the Babcock and Wilcox Co. The first two rows of entries on the right-hand page (p. 73), corresponding to their 1,000-kw and 5,000-kw open-pool reactors, are interchanged. Since four of the entries are identical for both reactors, the only quantities affected are critical mass, initial fuel loading, and price range.

HEALTH PHYSICISTS

throughout the world rely on the JUNO



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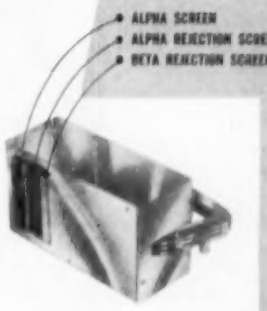

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NUCLEAR CALENDAR

March 11–15—1957 Nuclear Congress, will include four events, all at Convention Hall, Philadelphia: **A.** Second Nuclear Engineering & Science Congress (EJC), running all 5 days; contact T. A. Marshall Jr., ASME, 29 W 39, NYC 18. **B.** Fifth Atomic Energy for Industry conference (NICB), **14–15th**; contact E. A. Hammersfahr, NICB, 460 Park Ave., NYC. **C.** International Atomic Exposition, all 5 days; contact J. V. Friel, 304 Architects Bldg., Philadelphia 3. **D.** Fifth Hot Labs & Equipment Conference (Hot Laboratories Committee), **14–15th**; contact Frank Ring Jr., ORNL, Oak Ridge, Tenn.

March 18–27—National convention IRE, New York; professional group on nuclear science meets **20th** (*Waldorf*); exhibits (*Coliseum*). Contact IRE, 1 E. 79 St., NYC.

March 27–29—Colloquium on radiation effects on materials. (Office of Naval Research, and Glenn L. Martin Co.), Baltimore (*Johns Hopkins Univ.*). Contact Jerome Morse, Martin, Baltimore 3, Md.

April 29–May 1—Eighth annual spectroscopy symposium (Am. Assn. of Spectrographers), Chicago (*LaSalle*). Contact T. H. Zink, 4528 Division St., Chicago 51.

May 13–15—Second annual Industrial Nuclear Technology conference on applied uses of radiation (Armour Research Foundation and NUCLEONICS), Chicago (Museum of Science and Industry). Contact L. E. Reiffel, ARF, 55 E 33, Chicago.

May 28–29—Second reactive metals conference (So. California section AIME), Los Angeles (*Ambassador*). Contact B. S. Mesick, Arthur D. Little Inc., Los Angeles.

June 6–8—Third conference on nuclear structure (Univ. Pittsburgh), Pittsburgh. Contact Norman Austern, Sarah M. Scaife Radiation Laboratory, Univ. Pittsburgh.

June 15–Sept. 8—International exhibition "The Atom," near Schiphol airport, Amsterdam. Besides Holland, nine countries including US and USSR will participate.

June 24–26—Third annual meeting, American Nuclear Society, Pittsburgh (*Wm. Penn-Sheraton*). Contact W. W. Grigorieff, exec. secy., Box 963, Oak Ridge, Tenn.

Oct. 27–Nov. 1—Fourth annual meeting, Atomic Industrial Forum and third annual Trade Fair of Atomic Industry concurrently with fall meeting of American Nuclear Society, New York (*Coliseum*). Contact D. J. Scherer, AIF, 3 E. 54, NYC 22.

NEWSMAKERS

Harry D. Bruner takes over the medical branch of AEC's division of biology and medicine, succeeding **Roy E. Albert,** now teaching and doing research at George Washington University. Dr. Bruner, a former chief of the medical division at Oak Ridge Institute of Nuclear Studies, was chairman of the physiology department at Emory University the last four years.

Atomics International (NAA) has named **George V. Alevizon** project manager for the Organic Moderated Reactor Experiment being built at the Idaho reactor testing station, and **J. F. Trevillyan** project manager for the company's 5-watt research reactor, offered to small laboratories for training and research.

Olin-Mathieson has named **Edward Hartshorne** general manager of its nuclear fuel division.

Robert W. Schumann, formerly with Argonne, has been appointed chief development engineer at Radiation Counter Laboratories, Skokie, Ill.

John D. Rhule, formerly with Westinghouse's atomic division, is now staff engineer in the automatic control division at Teller Co., Butler, Pa.

William D. Miller and **Mervyn L. Barman** have joined the control systems division of Ramo-Wooldridge Corp.

Nicholas Anton, president of Anton Electronic Laboratories, was elected chairman of the Nuclear Instrumentation Manufacturers' Council.

Armour Research Foundation has assigned **Ray J. Van Thyne** to be supervisor of reactor metallurgy, in charge of a program of work on fuel elements, roll bonding, specialized corrosion problems, and development of high-temperature alloys; it will include research on uranium, thorium, zirconium and vanadium.

Zirconium Corp. of America, Solon, Ohio, has named **E. C. Sargent** president, succeeding **N. V. Coyle** who remains as board chairman. Sargent joined Zircoa in February as vice-president and general manager, had previously been a project manager at Vitro and Cleveland area manager for AEC.

General Atomic division of General Dynamics continues its recruiting for its Hopkins laboratory at San Diego. Appointments last month included **Park H. Miller Jr.,** professor of physics at Pennsylvania Univ. and a solid-state specialist; nuclear chemists **Roman Schmitt** and **Robert L. Wolke; Egil K. Bjørnerud,** nuclear physicist from the Rand Corp. and the Institute for Atomic Energy, Kjeller, Norway; and mathematician **William F. Brown** whose field is experimental and theoretical hydrodynamics.

Alan Andrew has moved from Atomics International to Lockheed Missile Systems division research labs as an atomic energy research specialist.

Crane Co. has assigned **Paul R. Kruesi** of its engineering division to be general manager of the chemical processing division in Heavy Minerals Co. at Chattanooga, Tenn. Heavy Minerals is a subsidiary of Crane, Vitro Corp., and the French metal firm Pechiney; it is engaged principally in mining, processing and sale of rare earths and heavy minerals including thorium.

John H. Jurik will direct the new Baton Rouge, La., office of Walter Kidde Constructors Inc., established to expedite the firm's design, engineering and construction projects in the south and southwest.

A reorganization of the Australian Federal Government has resulted in transfer of all matters involving atomic energy utilization and development including uranium resources from the Ministry of Supply to the Ministry of National Development. **Sen. William Henry Spooner,** Minister of National Development, takes over responsibility for the program from Minister of Supply **Howard Beale.** No policy changes are planned.

Baird Associates–Atomic Instrument Co. has named **Wilburt M. Draisin** promotions manager and **Arthur L. Krasnow** assistant sales manager.

Hamner Electronics Co., makers of nuclear and electronic instruments, has appointed **Ervine M. Rips** chief engineer.

On the tenth anniversary of the AEC's first meeting (Nov. 13, 1946), four officials received the AEC gold medal for distinguished service, highest recognition extended by the Commission. They were **Richard W. Cook,** deputy general manager; **Jesse C. Johnson,** director of the Raw Materials division; **William Mitchell,** general counsel, and **Charles Vanden Bulck,** assistant manager for administration of the Oak Ridge Operations Office. In addition 18 present and former employees were given silver medals for outstanding service, in what will become an annual awards ceremony.

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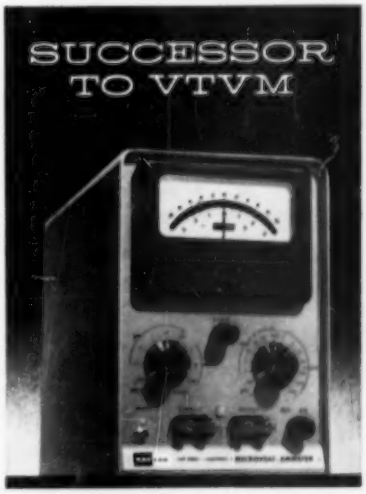

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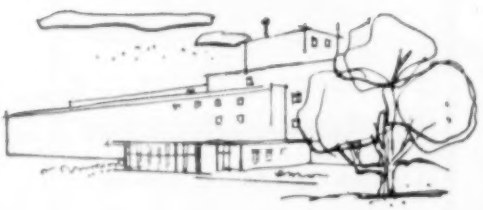

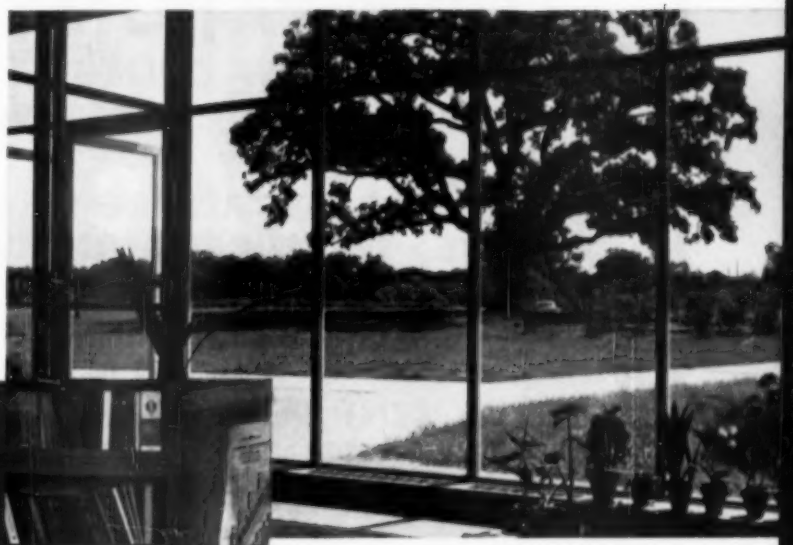

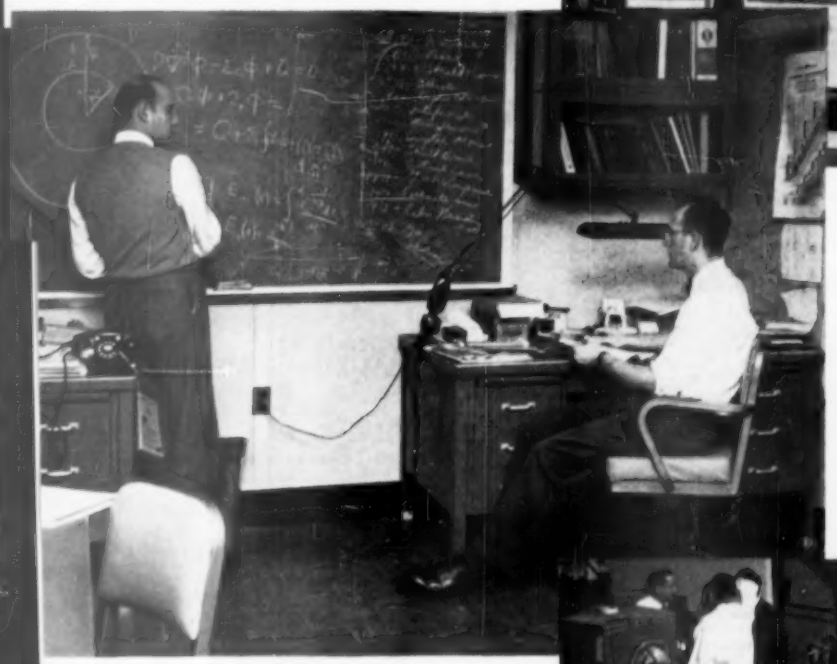

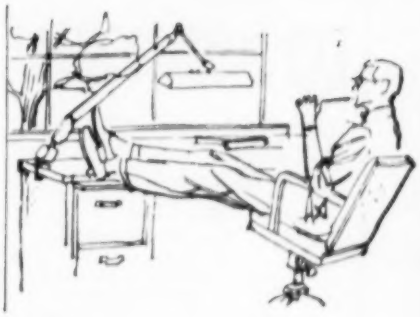

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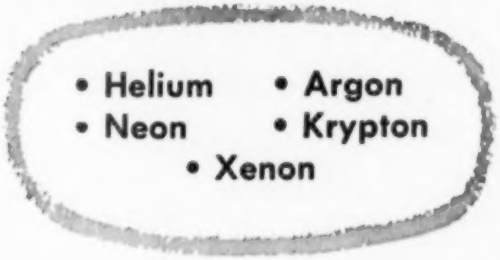

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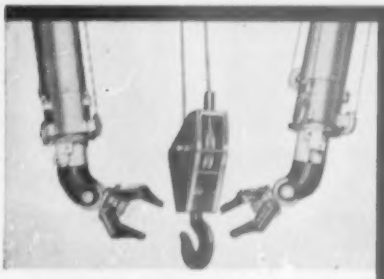

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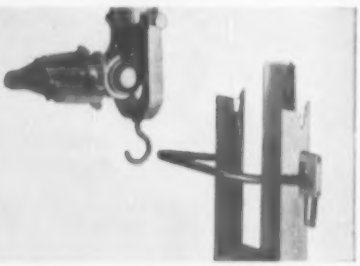
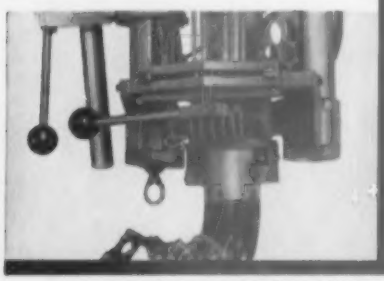
Special Purpose Tongs. For repetitive or highly specialized operations, specially-designed, remotely-interchangeable tongs can be supplied to increase speed and ease of operation.

Load Hook available for CRL Model 8 may be remotely attached or detached and permits a vertical lift of 60 pounds.





Motion Locks enable one to position rigidly in space any object which the manipulator can handle. Locking grip is standard equipment on all models. Locks for all other rotation, translation, and elevation motions are available as extra accessories.

For more information on special applications of CRL Master-Slave Manipulators, phone or write today to

Central Research **laboratories, inc.**

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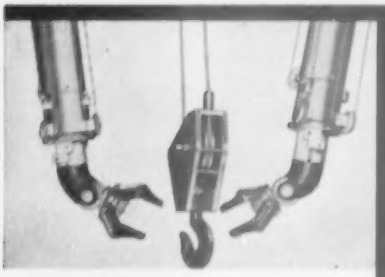
THE INDEX

TO THIS VOLUME HAS BEEN REMOVED FROM THIS POSITION AND PLACED AT THE BEGINNING OF THE FILM FOR THE CONVENIENCE OF READERS.

CRL manipulators
plus
CRL accessories
equals
versatility

One of the important characteristics leading to the choice of Master-Slave Manipulators for most hot cells currently being constructed is versatility. The wise buyer who obtains manipulators from Central Research Laboratories will be happy to know that a wide variety of accessories are available from CRL to augment this versatility.



Cranes and Hoists. Lifting and moving of heavy loads in hot-cell areas may be accomplished by remote-control cranes and hoists specially designed and manufactured by CRL for use with Master-Slave Manipulators.

Flexible Booting protects slave end of manipulator from dust, contamination, and corrosion. Restricted gas-flow seal possible. Does not interfere with any of the manipulator's natural movements.

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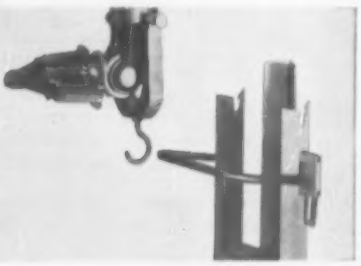

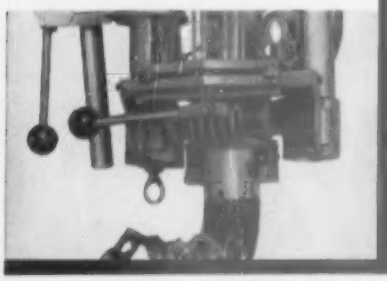

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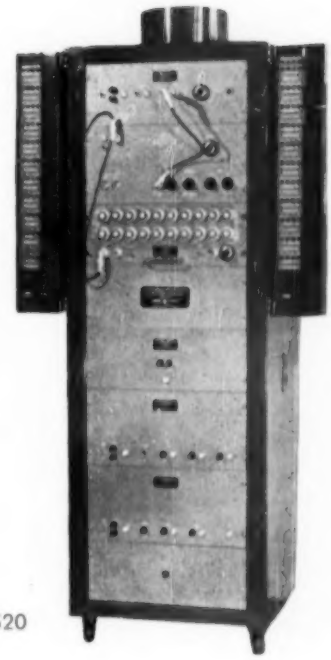
BAIRD ATOMIC

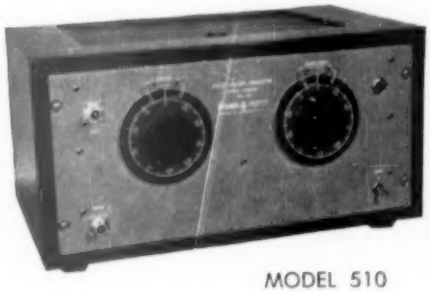
DIFFERENTIAL PULSE HEIGHT ANALYZERS



MODEL 520

MULTI-CHANNEL

- Twenty fixed adjacent channels (0.5 volt each) may be moved as a group over a 60 volt spectrum, dividing the spectrum into 120 parts.
- Many units in use in leading university and atomic energy laboratories over last few years with outstanding performance.
- Simultaneous pulse height measurements reduce operating time of expensive equipment used to produce data.
- Saves man hours of skilled scientific personnel.
- Rapid taking of isotope spectrum data eliminates decay corrections.
- A completely detailed professionally prepared instruction manual (over 100 pages) furnished with each instrument.



MODEL 510

SINGLE CHANNEL

- Hundreds of these units in use over the last 5 years have established the Model 510 Analyzer as the standard in radio-isotope laboratories.
- Used for studies of energy distribution of nuclear particles. Permits separate counting of isotopes in mixtures. Reduces background count to permit counting of low concentration or low energy isotopes.
- Furnished with final instruction book.

The Model 510 allows only those pulses falling between two set amplitudes to pass through to the output to be counted or recorded. Pulses above and below selected levels are rejected. Full range, 0-100 volts, channel width, 0-7 volts — both controlled by helical potentiometers.

Negative output variable to −15 volts. Model 510 may be used as an integral discriminator by setting channel width at 10 volts.

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- W. A. BROWN & ASSOCIATES, INC. — Alexandria, Va.
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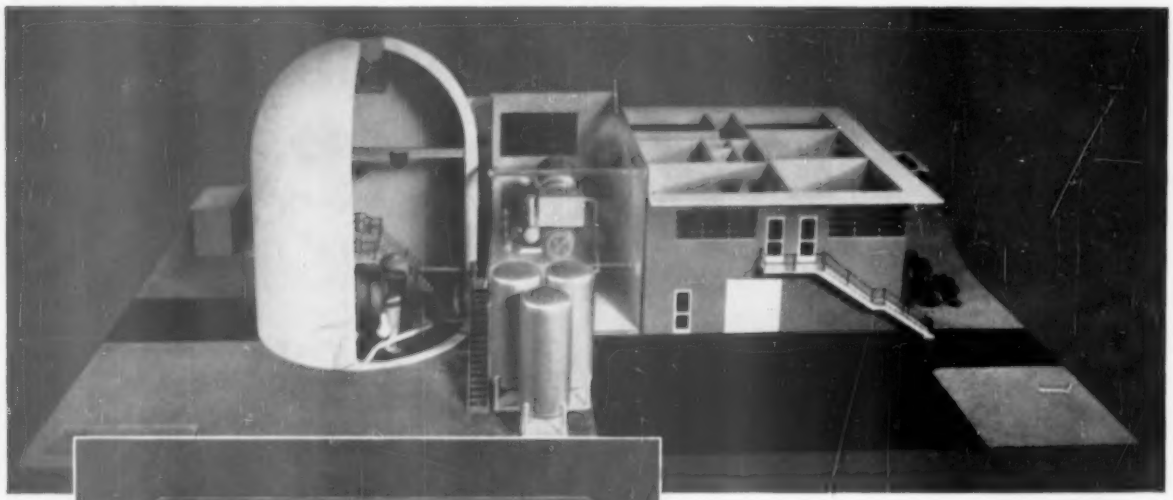
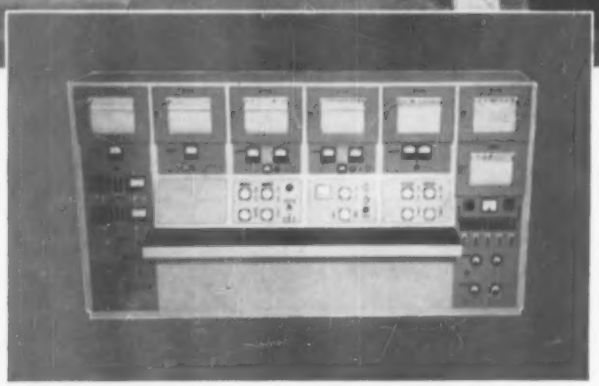


Model of the ALCO Packaged Power Plant. Nuclear power plants of this size —in which one charge of uranium may be sufficient for a year or more—range in output from 1800 to 2500 kw, or more.



Honeywell console used in the Army Packaged Power Reactor.

Honeywell controls will operate Army Packaged Power Reactor

THERE'S a new solution to the problem of providing power for radar, office machines, power tools, and all the other accoutrements of a modern army in the field. It's the Army Packaged Power Reactor, all of whose parts—reactor core, shielding, instrumentation, generator, enclosure—can be airlifted to a site. This packaged power plant can provide power in remote or occupied areas, where conventional fuels may be unobtainable or too costly, and where existing generating capacity may be inadequate.

Built by ALCO Products, Inc., the Army Packaged Power Reactor will be operated by a Honeywell control system. This control system is now being tested at Schenectady, N. Y.

Honeywell's Industrial Division designed and assembled the complete control console. The unit includes the exclusive Brown Safety Amplifier with fast-acting relays to initiate irreversible scram, a combined Log-N and Period Amplifier, an improved AID Linear Amplifier, and other outstanding Honeywell products. Embodied in the system are the experience and know-how gained by Honeywell nuclear engineers in designing control systems or components for reactors at Battelle Memorial Institute, North Carolina State University, and all major Atomic Energy Commission installations.

This is experience that can be applied to advantage in your own reactor project. Your nearby Honeywell sales engineer is ready to work with you on instrumentation techniques for any nuclear project. Call him today . . . he's as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, Wayne and Windrim Avenues, Philadelphia 44, Pa.—in Canada, Toronto 17, Ontario.

MINNEAPOLIS
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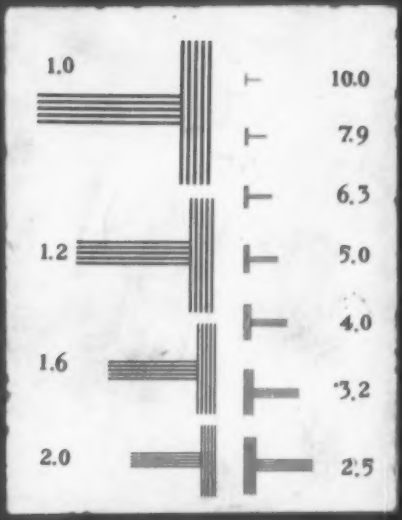
BROWN INSTRUMENTS
First in Controls

RESOLUTION CHART



100 MILLIMETERS

INSTRUCTIONS Resolution is expressed in terms of the lines per millimeter recorded by a particular film under specified conditions. Numerals in chart indicate the number of lines per millimeter in adjacent "T-shaped" groupings.

In microfilming, it is necessary to determine the reduction ratio and multiply the number of lines in the chart by this value to find the number of lines recorded by the film. As an aid in determining the reduction ratio, the line above is 100 millimeters in length. Measuring this line in the film image and dividing the length into 100 gives the reduction ratio. Example: the line is 20 mm. long in the film image, and $100/20 = 5$.

Examine "T-shaped" line groupings in the film with microscope, and note the number adjacent to finest lines recorded sharply and distinctly. Multiply this number by the reduction factor to obtain resolving power in lines per millimeter. Example: 7.9 group of lines is clearly recorded while lines in the 10.0 group are not distinctly separated. Reduction ratio is 5, and $7.9 \times 5 = 39.5$ lines per millimeter recorded satisfactorily. $10.0 \times 5 = 50$ lines per millimeter which are not recorded satisfactorily. Under the particular conditions, maximum resolution is between 39.5 and 50 lines per millimeter.

Resolution, as measured on the film, is a test of the entire photographic system, including lens, exposure, processing, and other factors. These rarely utilize maximum resolution of the film. Vibrations during exposure, lack of critical focus, and exposures yielding very dense negatives are to be avoided.